Webots User Guide

release 8.3.2

Copyright © 2015 Cyberbotics Ltd.

All Rights Reserved

www.cyberbotics.com

December 16, 2015

Permission to use, copy and distribute this documentation for any purpose and without fee is hereby granted in perpetuity, provided that no modifications are performed on this documentation.

The copyright holder makes no warranty or condition, either expressed or implied, including but not limited to any implied warranties of merchantability and fitness for a particular purpose, regarding this manual and the associated software. This manual is provided on an *as-is* basis. Neither the copyright holder nor any applicable licensor will be liable for any incidental or consequential damages.

The Webots software was initially developed at the Laboratoire de Micro-Informatique (LAMI) of the Swiss Federal Institute of Technology, Lausanne, Switzerland (EPFL). The EPFL makes no warranties of any kind on this software. In no event shall the EPFL be liable for incidental or consequential damages of any kind in connection with the use and exploitation of this software.

Trademark information

Aibo™is a registered trademark of SONY Corp.

Radeon™is a registered trademark of ATI Technologies Inc.

GeForce™is a registered trademark of nVidia, Corp.

Java™is a registered trademark of Sun MicroSystems, Inc.

Khepera™and Koala™are registered trademarks of K-Team S.A.

Linux™is a registered trademark of Linus Torvalds.

Mac OS X™is a registered trademark of Apple Inc.

Mindstorms™and LEGO™are registered trademarks of the LEGO group.

IPR™is a registered trademark of Neuronics AG.

Ubuntu™is a registered trademark of Canonical Ltd.

Visual C++™, Windows™, Windows NT™, Windows 2000™, Windows XP™, Windows Vista™, Windows 7™and Windows 8™are registered trademarks of Microsoft Corp.

UNIX™is a registered trademark licensed exclusively by X/Open Company, Ltd.

Foreword

Webots is a three-dimensional mobile robot simulator. It was originally developed as a research tool for investigating various control algorithms in mobile robotics.

This user guide will get you started using Webots. However, the reader is expected to have a minimal knowledge in mobile robotics, in C, C++, Java, Python or MATLAB programming, and in VRML97 (Virtual Reality Modeling Language).

Webots 8 features a new layout of the user interface with many facilities integrated, such as a source code editor, motion editor, etc.

We hope that you will enjoy working with Webots 8.

Thanks

Cyberbotics is grateful to all the people who contributed to the development of Webots, Webots sample applications, the Webots User Guide, the Webots Reference Manual, and the Webots web site, including Stefania Pedrazzi, David Mansolino, Yvan Bourquin, Fabien Rohrer, Jean-Christophe Fillion-Robin, Jordi Porta, Emanuele Ornella, Yuri Lopez de Meneses, Sébastien Hugues, Auke-Jan Ispeert, Jonas Buchli, Alessandro Crespi, Ludovic Righetti, Julien Gagnet, Lukas Hohl, Pascal Cominoli, Stéphane Mojon, Jérôme Braure, Sergei Poskriakov, Anthony Truchet, Alcherio Martinoli, Chris Cianci, Nikolaus Correll, Jim Pugh, Yizhen Zhang, Anne-Elisabeth Tran Qui, Grégory Mermoud, Lucien Epinet, Jean-Christophe Zufferey, Laurent Lessieux, Aude Billiard, Ricardo Tellez, Gerald Foliot, Allen Johnson, Michael Kertesz, Simon Garnieri, Simon Blanchoud, Manuel João Ferreira, Rui Picas, José Afonso Pires, Cristina Santos, Michal Pytasz and many others.

Moreover, many thanks are due to Cyberbotics's Mentors: Prof. Jean-Daniel Nicoud (LAMI-EPFL), Dr. Francesco Mondada (EPFL), Dr. Takashi Gomi (Applied AI, Inc.).

Finally, thanks to Skye Legon and Nathan Yawn, who proofread this guide.

Contents

1 Installing Webots **19**

1.1 Webots licenses . . . 19

1.1.1 Webots PRO . . . 19

1.1.2 Webots EDU . . . 19

1.1.3 Webots MOD . . . 20

1.1.4 Webots licences overview . . . 20

1.2 System requirements . . . 20

1.3 Verifying your graphics driver installation . . . 21

1.3.1 Supported graphics cards . . . 21

1.3.2 Unsupported graphics cards . . . 21

1.3.3 Upgrading your graphics driver . . . 22

1.3.4 Hardware acceleration tips . . . 23

1.4 Installation procedure . . . 24

1.4.1 Linux . . . 24

1.4.2 Windows . . . 26

1.4.3 Mac OS X . . . 27

1.5 Webots license system . . . 27

1.5.1 Firewall configuration (optional) . . . 27

1.5.2 License agreement . . . 28

1.5.3 License setup . . . 28

1.5.4 License administration . . . 28

1.5.5 Module download folder . . . 28

1.6 Classroom license setup . . . 29

1.6.1 User account . . . 29
1.6.2 Classrom . . . 31
1.6.3 Homework . . . 31
1.6.4 Using Webots without Internet connection . . . 32
1.7 Translating Webots to your own language . . . 32

2 Getting Started with Webots **33**
2.1 Introduction to Webots . . . 33
2.1.1 What is Webots? . . . 33
2.1.2 What can I do with Webots? . . . 33
2.1.3 What do I need to know to use Webots? . . . 34
2.1.4 Webots simulation . . . 34
2.1.5 What is a world? . . . 35
2.1.6 What is a controller? . . . 35
2.1.7 What is a Supervisor? . . . 35
2.2 Starting Webots . . . 36
2.2.1 Linux . . . 36
2.2.2 Mac OS X . . . 36
2.2.3 Windows . . . 36
2.2.4 Command Line Arguments . . . 36
2.3 The User Interface . . . 38
2.3.1 File Menu . . . 38
2.3.2 Edit Menu . . . 41
2.3.3 View Menu . . . 41
2.3.4 Simulation Menu . . . 43
2.3.5 Build Menu . . . 44
2.3.6 Robot Menu . . . 44
2.3.7 Tools Menu . . . 45
2.3.8 Wizards Menu . . . 45
2.3.9 Help menu . . . 46
2.3.10 Main toolbar . . . 46

2.3.11 Speedometer and Virtual Time . . . 47
2.4 The 3D Window . . . 47
2.4.1 Selecting an object . . . 47
2.4.2 Navigation in the scene . . . 48
2.4.3 Moving a solid object . . . 48
2.4.4 Applying a force to a solid object with physics . . . 49
2.4.5 Applying a torque to a solid object with physics . . . 50
2.4.6 Moving and resizing Overlays . . . 50
2.4.7 Show Camera and Display images in separate window . . . 50
2.5 The Scene Tree . . . 52
2.5.1 Field Editor . . . 52
2.6 Preferences . . . 54
2.6.1 General . . . 55
2.6.2 OpenGL . . . 55
2.7 Citing Webots . . . 56
2.7.1 Citing Cyberbotics' web site . . . 56
2.7.2 Citing a reference journal paper about Webots . . . 56

3 Sample Webots Applications 59
3.1 Samples . . . 59
3.1.1 blimp_lis.wbt . . . 60
3.1.2 gantry.wbt . . . 61
3.1.3 hexapod.wbt . . . 62
3.1.4 humanoid.wbt . . . 63
3.1.5 moon.wbt . . . 64
3.1.6 ghostdog.wbt . . . 65
3.1.7 salamander.wbt . . . 66
3.1.8 soccer.wbt . . . 67
3.1.9 sojourner.wbt . . . 68
3.1.10 yamor.wbt . . . 69
3.1.11 stewart_platform.wbt . . . 70

3.2 Webots Devices . . . 71
3.2.1 battery.wbt . . . 71
3.2.2 bumper.wbt . . . 72
3.2.3 camera.wbt . . . 73
3.2.4 connector.wbt . . . 74
3.2.5 distance_sensor.wbt . . . 75
3.2.6 emitter_receiver.wbt . . . 76
3.2.7 encoders.wbt . . . 77
3.2.8 force_sensor.wbt . . . 78
3.2.9 gps.wbt . . . 79
3.2.10 led.wbt . . . 80
3.2.11 light_sensor.wbt . . . 81
3.2.12 pen.wbt . . . 82
3.2.13 range_finder.wbt . . . 83
3.3 How To . . . 84
3.3.1 binocular.wbt . . . 84
3.3.2 biped.wbt . . . 85
3.3.3 force_control.wbt . . . 86
3.3.4 inverted_pendulum.wbt . . . 87
3.3.5 physics.wbt . . . 88
3.3.6 supervisor.wbt . . . 89
3.3.7 texture_change.wbt . . . 90
3.3.8 town.wbt . . . 91
3.4 Geometries . . . 92
3.5 Real Robots . . . 93
3.5.1 aibo_ers210_rough.wbt . . . 93
3.5.2 aibo_ers7.wbt . . . 94
3.5.3 alice.wbt . . . 95
3.5.4 boebot.wbt . . . 96
3.5.5 e-puck.wbt . . . 97
3.5.6 e-puck_line.wbt . . . 98

3.5.7 e-puck_line_demo.wbt . . . 99
3.5.8 hemisson_cross_compilation.wbt . . . 100
3.5.9 hoap2_sumo.wbt . . . 101
3.5.10 hoap2_walk.wbt . . . 102
3.5.11 ipr_collaboration.wbt . . . 103
3.5.12 ipr_cube.wbt . . . 104
3.5.13 ipr_factory.wbt . . . 105
3.5.14 ipr_models.wbt . . . 106
3.5.15 khepera.wbt . . . 107
3.5.16 khepera2.wbt . . . 108
3.5.17 khepera3.wbt . . . 109
3.5.18 khepera_kinematic.wbt . . . 110
3.5.19 khepera_gripper.wbt . . . 111
3.5.20 khepera_gripper_camera.wbt . . . 112
3.5.21 khepera_k213.wbt . . . 113
3.5.22 khepera_pipe.wbt . . . 114
3.5.23 khepera_tcpip.wbt . . . 115
3.5.24 koala.wbt . . . 116
3.5.25 magellan.wbt . . . 117
3.5.26 pioneer2.wbt . . . 118
3.5.27 rover.wbt . . . 119
3.5.28 scout2.wbt . . . 120
3.5.29 shrimp.wbt . . . 121
3.5.30 bioloid.wbt . . . 122

4 Language Setup **125**

4.1 Introduction . . . 125
4.2 Controller Start-up . . . 125
4.3 Using C . . . 126
4.3.1 Introduction . . . 126
4.3.2 C/C++ Compiler Installation . . . 127

4.4 Using C++ . . . 127
4.4.1 Introduction . . . 127
4.4.2 C++ Compiler Installation . . . 128
4.4.3 Source Code of the C++ API . . . 128
4.5 Using Java . . . 128
4.5.1 Introduction . . . 128
4.5.2 Java and Java Compiler Installation . . . 128
4.5.3 Link with external jar files . . . 130
4.5.4 Source Code of the Java API . . . 130
4.6 Using Python . . . 131
4.6.1 Introduction . . . 131
4.6.2 Python Installation . . . 131
4.6.3 Source Code of the Python API . . . 132
4.7 Using MATLAB . . . 132
4.7.1 Introduction to MATLAB™ . . . 132
4.7.2 How to run the Examples? . . . 132
4.7.3 MATLAB™Installation . . . 133
4.7.4 Display information to Webots console . . . 133
4.7.5 Compatibility Issues . . . 134
4.8 Using ROS . . . 134
4.8.1 What is ROS? . . . 134
4.8.2 ROS for Webots . . . 135
4.9 Interfacing Webots to third party software with TCP/IP . . . 137
4.9.1 Overview . . . 137
4.9.2 Main advantages . . . 137
4.9.3 Limitations . . . 138

5 Development Environments **139**
5.1 Webots Built-in Editor . . . 139
5.1.1 Compiling with the Source Code Editor . . . 139
5.2 The standard File Hierarchy of a Project . . . 141

5.2.1 The Root Directory of a Project . . . 141
5.2.2 The Project Files . . . 142
5.2.3 The ”controllers” Directory . . . 142
5.3 Compiling Controllers in a Terminal . . . 142
5.3.1 Mac OS X and Linux . . . 142
5.3.2 Windows . . . 143
5.4 Using Webots Makefiles . . . 143
5.4.1 What are Makefiles . . . 143
5.4.2 Controller with Several Source Files (C/C++) . . . 144
5.4.3 Using the Compiler and Linker Flags (C/C++) . . . 144
5.5 Debugging C/C++ Controllers . . . 146
5.5.1 Controller processes . . . 146
5.5.2 Using the GNU debugger with a controller . . . 147
5.6 Using Visual C++ with Webots . . . 148
5.6.1 Introduction . . . 148
5.6.2 Configuration . . . 149
5.7 Starting Webots Remotely (ssh) . . . 151
5.7.1 Using the ssh command . . . 151
5.7.2 Terminating the ssh session . . . 152
5.8 Transfer to your own robot . . . 152
5.8.1 Remote control . . . 153
5.8.2 Cross-compilation . . . 154
5.8.3 Interpreted language . . . 154

6 Programming Fundamentals 155
6.1 Controller Programming . . . 155
6.1.1 Hello World Example . . . 155
6.1.2 Reading Sensors . . . 156
6.1.3 Using Actuators . . . 158
6.1.4 How to use wb_robot_step() . . . 160
6.1.5 Using Sensors and Actuators Together . . . 160

6.1.6 Using Controller Arguments . . . 162
6.1.7 Controller Termination . . . 163
6.1.8 Shared libraries . . . 165
6.1.9 Environment variables . . . 165
6.1.10 Languages settings . . . 167
6.2 Supervisor Programming . . . 167
6.2.1 Introduction . . . 168
6.2.2 Tracking the Position of Robots . . . 168
6.2.3 Setting the Position of Robots . . . 169
6.3 Using Numerical Optimization Methods . . . 171
6.3.1 Choosing the correct Supervisor approach . . . 171
6.3.2 Resetting the robot . . . 173
6.4 C++/Java/Python . . . 176
6.4.1 Classes and Methods . . . 177
6.4.2 Controller Class . . . 177
6.4.3 C++ Example . . . 179
6.4.4 Java Example . . . 180
6.4.5 Python Example . . . 181
6.5 Matlab . . . 181
6.5.1 Using the MATLAB™desktop . . . 182
6.6 Controller Plugin . . . 183
6.6.1 Fundamentals . . . 183
6.6.2 Robot Window Plugin . . . 184
6.6.3 Qt utility library . . . 186
6.6.4 Motion editor . . . 187
6.6.5 Remote-control Plugin . . . 188
6.7 Webots Plugin . . . 189
6.7.1 Physics Plugin . . . 190

7 Tutorials **191**

7.1 Prerequisites . . . 192
7.1.1 Install Webots . . . 192
7.1.2 Create a directory for all your Webots files . . . 192
7.1.3 Start Webots . . . 192
7.1.4 Create a new Project . . . 193
7.1.5 The Webots Graphical User Interface (GUI) . . . 193
7.2 Tutorial 1: Your first Simulation in Webots (20 minutes) . . . 193
7.2.1 Create a new World . . . 195
7.2.2 Add an e-puck Robot . . . 197
7.2.3 Create a new Controller . . . 199
7.2.4 Conclusion . . . 201
7.3 Tutorial 2: Modification of the Environment (20 minutes) . . . 201
7.3.1 A new Simulation . . . 201
7.3.2 Modification of the Floor . . . 201
7.3.3 The Solid Node . . . 202
7.3.4 Create a Ball . . . 203
7.3.5 Geometries . . . 204
7.3.6 DEF-USE mechanism . . . 204
7.3.7 Add Walls . . . 205
7.3.8 Efficiency . . . 207
7.3.9 Conclusion . . . 207
7.4 Tutorial 3: Appearance (15 minutes) . . . 208
7.4.1 New simulation . . . 208
7.4.2 Lights . . . 208
7.4.3 Modify the Appearance of the Walls . . . 209
7.4.4 Add a Texture to the Ball . . . 209
7.4.5 Rendering Options . . . 210
7.4.6 Conclusion . . . 210
7.5 Tutorial 4: More about Controllers (20 minutes) . . . 210
7.5.1 New World and new Controller . . . 211

7.5.2 Understand the e-puck Model . . . 211
7.5.3 Program a Controller . . . 212
7.5.4 The Controller Code . . . 216
7.5.5 Conclusion . . . 218
7.6 Tutorial 5: Compound Solid and Physics Attributes (15 minutes) . . . 218
7.6.1 New simulation . . . 219
7.6.2 Compound Solid . . . 219
7.6.3 Physics Attributes . . . 220
7.6.4 The Rotation Field . . . 221
7.6.5 How to choose bounding Objects? . . . 221
7.6.6 Contacts . . . 222
7.6.7 basicTimeStep, ERP and CFM . . . 222
7.6.8 Minor physics Parameters . . . 222
7.6.9 Conclusion . . . 223
7.7 Tutorial 6: 4-Wheels Robot . . . 223
7.7.1 New simulation . . . 223
7.7.2 Separating the Robot in Solid Nodes . . . 223
7.7.3 HingeJoints . . . 226
7.7.4 Sensors . . . 227
7.7.5 Controller . . . 227
7.7.6 Conclusion . . . 228
7.8 Tutorial 7: Using ROS . . . 229
7.8.1 Creating a Webots project that contains a ROS package . . . 229
7.8.2 Conclusion . . . 233
7.9 Going Further . . . 233

8 Robots **235**

8.1 Using the e-puck robot . . . 235
8.1.1 Overview of the robot . . . 235
8.1.2 Simulation model . . . 236
8.1.3 Control interface . . . 240

8.2 Using the Nao robot . . . 245
8.2.1 Introduction . . . 245
8.2.2 Using Webots with Choregraphe . . . 245
8.2.3 Nao models . . . 246
8.2.4 Using motion boxes . . . 246
8.2.5 Using the cameras . . . 247
8.2.6 Using Several Nao robots . . . 247
8.2.7 Getting the right speed for realistic simulation . . . 248
8.2.8 Known Problems . . . 248
8.3 Using the Thymio II robot . . . 249
8.3.1 Thymio II model . . . 249
8.3.2 Connect Aseba to the Thymio II model . . . 250
8.3.3 Thymio II Pen . . . 251
8.3.4 Thymio II Ball . . . 253
8.4 Using the Pioneer 3-AT and Pioneer 3-DX robots . . . 253
8.4.1 Pioneer 3-AT . . . 253
8.4.2 Pioneer 3-DX . . . 256

9 Webots FAQ 261
9.1 General FAQ . . . 261
9.1.1 What are the differences between Webots PRO, Webots EDU and other Webots modules? . . . 261
9.1.2 How can I report a bug in Webots? . . . 261
9.1.3 Is it possible to use Visual C++ to compile my controllers? . . . 262
9.2 Programming . . . 262
9.2.1 How can I get the 3D position of a robot/object? . . . 262
9.2.2 How can I get the linear/angular speed/velocity of a robot/object? . . . 263
9.2.3 How can I reset my robot? . . . 264
9.2.4 What does this mean: ”Could not find controller {...} Loading void controller instead.” ? . . . 264
9.2.5 What does this mean: ”Warning: invalid WbDeviceTag in API function call” ? . . . 265

9.2.6 Is it possible to apply a (user specified) force to a robot? . . . 266
9.2.7 How can I draw in the 3D window? . . . 267
9.2.8 What does this mean: ”The time step used by controller {...} is not a multiple of WorldInfo.basicTimeStep!”? . . . 267
9.2.9 How can I detect collisions? . . . 268
9.2.10 Why does my camera window stay black? . . . 269
9.3 Modeling . . . 269
9.3.1 My robot/simulation explodes, what should I do? . . . 269
9.3.2 How to make replicable/deterministic simulations? . . . 270
9.3.3 How to remove the noise from the simulation? . . . 271
9.3.4 How can I create a passive joint? . . . 271
9.3.5 Is it possible fix/immobilize one part of a robot? . . . 271
9.3.6 Should I specify the ”mass” or the ”density” in the Physics nodes? . . . 272
9.3.7 How to get a realisitc and efficient rendering? . . . 272
9.4 Speed/Performance . . . 273
9.4.1 Why is Webots slow on my computer? . . . 273
9.4.2 How can I change the speed of the simulation? . . . 273

10 Known Bugs **275**
10.1 General bugs . . . 275
10.1.1 Intel GMA graphics cards . . . 275
10.1.2 Virtualization . . . 275
10.1.3 Collision detection . . . 275
10.1.4 Orientation dependent friction . . . 276
10.2 Mac OS X . . . 276
10.2.1 Matlab and robot plugins . . . 276
10.3 Linux . . . 276
10.3.1 Window refresh . . . 276
10.3.2 ssh -x . . . 276

Chapter 1

Installing Webots

This chapter explains how to install Webots and configure your license rights.

1.1 Webots licenses

The Webots licenses comes in three different flavors, including Webots PRO, Webots EDU and Webots MOD. They differ by the features and price. These different versions are described in this section. The features available in the different versions are summarized in table 1.1.

1.1.1 Webots PRO

Webots PRO is the most powerful version of Webots. It is designed for research and development projects. Webots PRO includes the possibility to create supervisor processes for controlling robotics experiments, an extended physics programming capability and a fast simulation mode (faster than real time). A 30 day trial version of Webots PRO is available from Cyberbotics web site.

1.1.2 Webots EDU

Webots EDU is tailored for classrooms. Students learn how to model robots, create their own environments and program the behavior of the robots, using any of the supported programming languages. To validate their models, they can optionally transfer their control programs to real robots. A 30 day trial version of Webots EDU is available upon request.

1.1.3 Webots MOD

Webots MOD is a special license mode in which the simulation software comes free of charge and the users pay only for the modules they need. Various modules are available for purchase at different price tags. They include special robot models (e.g., NAO, DARwIn-OP, e-puck, Thymio 2, etc.), object models (e.g., cardboard box, wooden box, etc.), environment models (e.g., robot soccer field), programming libraries, programming languages (e.g., C/C++, Matlab, Python), interfaces to third parties software or hardware, etc. They are all described on Cyberbotics web site.

1.1.4 Webots licences overview

The following table summarizes the main differences between Webots PRO, Webots EDU and Webots MOD.

Webots feature	PRO	EDU	MOD
Supervisor capability	yes	no	no
Physics plug-in programming	yes	no	no
Fast simulation mode	yes	no	no
Robot and environment modelling	yes	yes	no
Robot programming	yes	yes	yes/no (1)
Transfer to real robots	yes	yes	yes/no (1)
Multi-platform: Windows, Mac & Linux	yes	yes	yes
Floating licenses	yes	yes	yes
One year Premier Service included	yes	yes	yes

Table 1.1: Webots licenses summary

(1): refer to specific module description.

1.2 System requirements

The following hardware is required to run Webots:

- A fairly recent PC or Macintosh computer with at least a 2 GHz dual core CPU clock speed and 2 GB of RAM is a minimum requirement. A quad-core CPU is however recommended.
- An nVidia or AMD (formerly ATI) OpenGL (minimum version 2.1) capable graphics adapter with at least 512 MB of RAM is required. We do not recommend any other graphics adapters, including Intel graphics adapters, as they often lack a good OpenGL support which may cause 3D rendering problems and application crashes. Nevertheless, in some

cases, the installation of the latest Intel graphics driver can fix such problems and let you use Webots. However, we don't provide any guarantee on this. For Linux systems, we recommend only nVidia graphics cards. Webots works well on all the graphics cards included in fairly recent Apple computers. It is strongly advised to try the 30 day trial version of Webots on your computer systems to ensure they are compatible before you buy.

The following operating systems are supported:

- Linux: Webots is ensured to run on the latest Ubuntu Long Term Support (LTS) release, currently version 14.04. But it is also known to run on most recent major Linux distributions, including RedHat, Mandrake, Debian, Gentoo, SuSE, and Slackware. We recommend using a recent version of Linux. Webots is provided for Linux 64 (x86-64) systems. Since Webots 8.1.0, the Linux 32 (i386) version is no longer provided. Webots doesn't run on Ubuntu version eariler than 12.04.
- Windows: Webots runs on Windows 10 64-bit, Windows 8.1 64-bit, Windows 8 64-bit and Windows 7 64-bit. It is not supported on 32-bit versions of Windows and on old versions including Windows Vista, XP, NT4 or 2000.
- Macintosh: Webots runs on Mac OS X 10.11 "El Captan" and 10.10 "Yosemite". Webots may work but is not officially supported on earlier versions of Mac OS X. Since version 6.3.0, Webots is compiled exclusively for Intel Macs, it does not run on old PowerPC Macs. To use Webots on a PowerPC Mac, you need Webots 6.2.4 (or earlier), these older versions were compiled as *Universal Binary*.

Other versions of Webots for other UNIX systems (Solaris, Linux PPC, Irix) may be available upon request.

1.3 Verifying your graphics driver installation

1.3.1 Supported graphics cards

Webots officially supports only recent nVidia and ATI graphics adapters. So it is recommended to run Webots on computers equipped with such graphics adapters and up-to-date drivers provided by the card manufacturer (i.e., nVidia or ATI). Such drivers are often bundled with the operating system (Windows, Linux and Mac OS X), but in some case, it may be necessary to fetch it from the web site of the card manufacturer.

1.3.2 Unsupported graphics cards

Webots may nevertheless work with other graphics adapters, in particular the Intel graphics adapters. However this is unsupported and may work or not, without any guarantee. Some

users reported success with some Intel graphics cards after installing the latest version of the driver. Graphics drivers from Intel may be obtained from the Intel download center web site[1]. Linux graphics drivers from Intel may be obtained from the Intel Linux Graphics web site[2]. If some graphical bugs subsist, changing the "RTT prefered mode" from the Webots OpenGL Preferences from "Framebuffer Object" to "Pixelbuffer Object" or "Direct Copy" may fix the problems. However, this may also impact the 3D performance.

1.3.3 Upgrading your graphics driver

On Linux and Windows, you should make sure that the latest graphics driver is installed. On the Mac the latest graphics driver are automatically installed by the *Software Update*, so Mac users are not concerned by this section. Note that Webots can run up to 10x slower without appropriate driver. Updating your driver may also solve various problems, i.e., odd graphics rendering or Webots crashes.

Linux

On Linux, use this command to check if a hardware accelerated driver is installed:

```
$ glxinfo | grep OpenGL
```

If the output contains the string "NVIDIA", "ATI", or "Intel", this indicates that a hardware driver is currently installed:

```
$ glxinfo | grep OpenGL
OpenGL vendor string: NVIDIA Corporation
OpenGL renderer string: GeForce 8500 GT/PCI/SSE2
OpenGL version string: 3.0.0 NVIDIA 180.44
...
```

If you read "Mesa", "Software Rasterizer" or "GDI Generic", this indicates that the hardware driver is currently not installed and that your computer is currently using a slow software emulation of OpenGL:

```
$ glxinfo | grep OpenGL
OpenGL vendor string: Mesa project: www.mesa3d.org
OpenGL renderer string: Mesa GLX Indirect
OpenGL version string: 1.4 (1.5 Mesa 6.5.2)
...
```

In this case you should definitely install the hardware driver.

On Ubuntu the driver can usually be installed automatically from the **Additional Drivers** tab of the **Software & Update** window. Otherwise you can find out what graphics hardware is installed on your computer by using this command:

[1] http://downloadcenter.intel.com
[2] http://intellinuxgraphics.org

```
$ lspci | grep VGA
01:00.0 VGA compatible controller: nVidia Corporation GeForce 8500 GT
    (rev a1)
```

Then you can normally download the appropriate driver from the graphics hardware manufacturer's website: http://www.nvidia.com[3] for an nVidia card or http://www.amd.com[4] for a ATI graphics card. Please follow the manufacturer's instructions for the installation.

Windows

1. Right-click on `My Computer`.
2. Select `Properties`.
3. Click on the `Device Manager` tab.
4. Click on the plus sign to the left of `Display adapters`. The name of the driver appears. Make a note of it.
5. Go to the web site of your card manufacturer: http://www.nvidia.com[5] for an nVidia card or http://www.amd.com[6] for a ATI graphics card.
6. Download the driver corresponding to your graphics card.
7. Follow the instructions from the manufacturer to install the driver.

1.3.4 Hardware acceleration tips

Linux

Depending on the graphics hardware, there may be a huge performance drop of the rendering system (up to 10x) when *compiz* desktop effects are on. Also these visual effects may cause some display bug where the main window of Webots is not properly refreshed. Hence, on Ubuntu (or other Linux) we recommend to deactivate the desktop effects. You can easily disable them using some tools like *Compiz Config Settings Manager* or *Unity Twerk Tool*.

[3] `http://www.nvidia.com`
[4] `http://www.amd.com`
[5] `http://www.nvidia.com`
[6] `http://www.amd.com`

1.4 Installation procedure

Usually, you will need to be ”administrator” to install Webots. Once installed, Webots can be used by a regular, unprivileged user. To install Webots, please follow this procedure:

1. Uninstall completely any old version of Webots that may have been installed on your computer previously.
2. Install Webots for your operating system as explained below.

After installation, the most important Webots features will be available, but some third party tools (such as Java, Python, or MATLAB™) may be necessary for running or compiling specific projects. The chapter 4 covers the set up of these tools.

1.4.1 Linux

Webots will run on most recent Linux distributions running glibc2.11.1 or earlier. This includes fairly recent Ubuntu, Debian, Fedora, SuSE, RedHat, etc. Webots comes in two different package types: `.deb` and `.tar.bz2` (tarball). The `.deb` package is aimed at the latest Ubuntu Linux distribution whereas the tarball package includes many dependency libraries and there is therefore best suited for installation on other Linux distributions. These packages can be downloaded from our web site[7].

Some of the following commands requires the `root` *privileges. You can get these privileges by preceding all the commands by the* `sudo` *command.*

Webots will run much faster if you install an accelerated OpenGL drivers. If you have a nVidia or ATI graphics card, it is highly recommended that you install the Linux graphics drivers from these manufacturers to take the full advantage of the OpenGL hardware acceleration with Webots. Please find instructions here section 1.3.

Webots needs the avconv *program to create MPEG-4 movies, that can be installed with* libav-tools *and* libavcodec-extra-54 *packages.*

[7] `http://www.cyberbotics.com/linux`

Using Advanced Packaging Tool (APT)

The advantage of this solution is that Webots will be updated with the system updates. This installation requires the `root` privileges.

First of all, you may want to configure your apt package manager by adding this line:

```
deb http://www.cyberbotics.com/debian/ binary-i386/
```

or

```
deb http://www.cyberbotics.com/debian/ binary-amd64/
```

in the `/etc/apt/sources.list` configuration file. Then update the APT packages by using

```
apt-get update
```

Optionally, Webots can be autentified thanks to the `Cyberbotics.asc` signature file which can be downloaded here[8], using this command:

```
apt-key add /path/to/Cyberbotics.asc
```

Then proceed to the installation of Webots using:

```
apt-get install webots
```

This procedure can also be done using any APT front-end tool such as the Synaptic Package Manager. But only a command line procedure is documented here.

From the tarball package

This section explains how to install Webots from the tarball package (having the `.tar.bz2` extension). This package can be installed without the `root` privileges. It can be uncompressed anywhere using the `tar xjf` command line. Once uncompressed, it is recommended to set the WEBOTS_HOME environment variable to point to the webots directory obtained from the uncompression of the tarball:

```
tar xjf webots-8.3.2-i386.tar.bz2
```

or

```
tar xjf webots-8.3.2-x86-64.tar.bz2
```

and

```
export WEBOTS_HOME=/home/username/webots
```

[8] `http://www.cyberbotics.com/linux`

The export line should however be included in a configuration script like `/etc/profile`, so that it is set properly for every session.

Some additional libraries are needed in order to properly run Webots. In particular *libjpeg62*, *libav-tools*, *libpci* and *libavcodec-extra-54* have to be installed on the system.

From the DEB package

This procedure explains how to install Webots from the DEB package (having the `.deb` extension).

On Ubuntu, double-click on the DEB package file to open it with the Ubuntu Software Center and click on the **Install** button. If a previous version of Webots is already installed, then the text on the button could be different, like **Upgrade** or **Reinstall**.

Alternatively, the DEB package can also be installed using `dpkg` or `gdebi` with the `root` privileges. For 32-bit systems:

```
dpkg -i webots_8.3.2_i386.deb
apt-get -f install
```

or

```
gdebi webots_8.3.2_i386.deb
```

For 64-bit systems:

```
dpkg -i webots_8.3.2_amd64.deb
apt-get -f install
```

or

```
gdebi webots_8.3.2_amd64.deb
```

1.4.2 Windows

1. Download the `webots-8.3.2_setup.exe` installation file from our web site[9].
2. Double click on this file.
3. Follow the installation instructions.

It is possible to install Webots silently from an administrator DOS console, by typing `webots-8.3.2_setup.exe/SILENT` or `webots-8.3.2_setup.exe/VERYSILENT`

If you observe 3D rendering anomalies or Webots crashes, it is strongly recommend to upgrade your graphics driver.

[9] `http://www.cyberbotics.com/windows`

1.4.3 Mac OS X

1. Download the `webots-8.3.2.dmg` installation file from our web site[10].
2. Double click on this file. This will mount on the desktop a volume named `Webots` containing the `Webots` folder.
3. Move this folder to your `/Applications` folder or wherever you would like to install Webots.

1.5 Webots license system

Starting with Webots 8, a new license system was introduced to facilitate the use of Webots, which replaces the previous system. Webots licenses can now be set-up on an unlimited number of computers, allowing you to use Webots seamlessly on any computer (office, home, travel, etc.). This new system relies on a license server located on Cyberbotics servers and accessible through an Internet connection. If you would like to use Webots while not connected to the Internet, you can transfer your Internet license from the server to your local computer for a limited duration. After the expiration of this duration, your license will be automatically transferred back to the license server.

Cyberbotics license servers are located in Switzerland on a highly reliable network featuring a 99.9% up-time. However, if for some reason our servers would fail, a security system will allow you to run Webots even in case of server failure, by connecting automatically to an alternate server located in the Cloud (hosted on Google App Engine).

1.5.1 Firewall configuration (optional)

If you plan to use Webots behind an Internet firewall, you should create two new rules in your firewall configuration to allow connections to the following servers:

- `https://www.cyberbotics.com (port 443)`
- `https://webots-license.appspot.com (port 443)`

If you are using a proxy to access the Internet, Webots will retrieve your system proxy configuration automatically.

[10] `http://www.cyberbotics.com/macosx`

1.5.2 License agreement

Please read your license agreement carefully before using Webots. This license is provided within the software package. By using the software and documentation, you agree to abide by all the provisions of this license.

1.5.3 License setup

A Webots license is originally associated with an e-mail address which corresponds to a user account on Cyberbotics's web site.

When Webots is started for the first time, a login dialog invites you to register a user account on Cyberbotics's web site (if not already done) and to enter the corresponding license information to log in your Webots session.

*The **Synchronization** field of the Webots login dialog defines how frequently Webots checks the license server. Setting this field to a small value will cause more networking activity, but will allow you to release the license quickly after a crash. This will allow you in turn to restart Webots quicker on another machine. For example, if you select 5 minutes, you may have to wait for up to 5 minutes if you crashed Webots on a machine and want to restart it on another.*

1.5.4 License administration

If you are the administrator of the license, you can log into your Webots account on Cyberbotics' web site and go to the **Administration** page under the **My Account** tab. From there, you will be able to monitor your licenses, to purchase more licenses, to create groups of users and to grant customized user access to your licenses.

1.5.5 Module download folder

By default, Webots will download the different modules you purchased and store them in the local user application folder:

- Windows: `C:\Users\MyName\AppData\Local\Cyberbotics\Webots\8.0`
- Mac OS X: `/Users/MyName/Library/ApplicationSupport/Cyberbotics/Webots/8.0`
- Linux: `/home/MyName/.local/share/Cyberbotics/Webots/8.0`

You may want to change this behavior and have Webots storing its module files in a different folder. This is possible by setting the `WEBOTS_MODULES_PATH` environment variable to point to a folder where the modules files will be downloaded and stored. It can be useful to do so if you want to avoid that each user has its own copy of the module files. In such a case, it is recommended for the users to start Webots with the `--disable-modules-download` option to avoid overwritting files in this folder.

If you need further information about license issues, please send an e-mail to:

`<license@cyberbotics.com>`

1.6 Classroom license setup

This section explains how to setup your Webots licenses to grant access to students in a classroom. It also explains how to manage student access to Webots licenses for homework Webots exercices or projects. Let's assume you purchased 20 licenses of Webots EDU and want to let some of your students use them. You should ensure that your classroom machines can access the Internet and in particular the license server of Cyberbotics[11]. If it doesn't work, you may need to configure your local firewall to allow Webots to access this URL.

1.6.1 User account

There are two methods to handle student access to Webots licenses: a single user account, or multiple user accounts.

Single user account

The single user account method is simpler to setup as you don't need to know the e-mail addresses of the students. Nevertheless, you need to setup an e-mail address for a generic user for which you can read the e-mails received. It could be your own personal e-mail address. Let's call this e-mail address `webots@my.university.edu`. A drawback to this method is that it allows a single student to use simultaneously several instances of your 20 licenses, possibly all of them, thus preventing other students to use them.

1. Log in to your Webots user account using your license administration credentials, e.g., the user account which was used to activate your Webots licenses.
2. Create a new user pack from the administration page and call it "Students".
3. Grant access to all your 20 Webots EDU license (tick boxes).

[11] `https://www.cyberbotics.com/license`

4. Set the concurrency value to 20 to allow the single user account to use all the licenses simultaneously.

5. Type `webots@my.university.edu` in the "users:" text area.

6. If the account doesn't already exists, `webots@my.university.edu` will receive an e-mail asking to create a user account at Cyberbotics' web site[12].

7. Create this account (if needed), log in and visit the Profile page of this account. Copy the "Alternate password for Webots 8". This password allows students to use Webots, but not to log in this user account. It looks like `J6ebgAGRgFtkf8QHiWoHXIUnI98=`.

8. Give this e-mail address and alternate password to your students to allow them to log in Webots using your licenses (but they won't be able to log in the web page).

Multiple user accounts

The multiple user accounts license requires that you have the list of e-mail addresses of the students to whom you want to grant access to your Webots licenses. You will be able to limit the number of simultaneous instances of Webots used per student to 1, so that a single student cannot use multiple licenses simultaneously. Hence a single student cannot prevent the others from using Webots.

1. Log in to your Webots user account using your license administration credentials, e.g., the user account which was used to activate your Webots licenses.

2. Create a new user pack from the administration page and call it "Students".

3. Grant access to all your 20 Webots EDU license (tick boxes).

4. Set the concurrency value to 1 to prevent a single user to use multiple instances of Webots at the same time.

5. Type (or copy/paste) the list of student e-mail addresses in the "users:" text area.

6. Press the apply button. The e-mail addresses which are not already registered on Cyberbotics' web site will receive an invitation e-mail explaining how to register a Webots account and use the newly granted Webots licenses. For existing accounts, no e-mail is sent and it is your responsibility to inform the students about their modified license rights.

[12] `https://www.cyberbotics.com`

1.6.2 Classrom

Setup

You can install Webots on all the computers in a classroom, even if you have more computers than licenses. In our example, if you have 20 licenses and 30 computers, then 20 students could use the software simultaneously on any of the 30 computers. If a 21rst student comes in, he won't be able to start Webots until one of the 20 students stops using Webots.

Restrict the license to specific machines

It is possible to restrict the use of your licenses to a specific classroom, or more generally, to a number of specific computers. This can be achieved from the "Module pack" section of the administration web page: click on the license you want to restrict and a new page entitled "Edit module pack" should be displayed. On this page, set an IP range value to limit the use of this pack to machines with a specific IP address. For example: "128.179.67.143, 128.179.67.146, 123.179.67.145" will limit the use of Webots to these 3 IP addresses. It is also possible to use an IP mask (CIDR notation) to specify a range of IP addresses. For example, "128.179.67.143/24, 128.178.12.122" will limit the use of Webots to any machine whose IP address starts with 128.179.67 and also to the machine whose IP address is 128.178.12.122. Machines that do not match the values provided in the IP range field won't be able to access the licenses.

Making things even simpler for students

To save the students from having to type an e-mail address and password on the first run of Webots, you may want to do it for them before the class starts. If you do it from the user account they are supposed to use, this information will be saved and the students won't need to enter it again. You may also automate this process by copying an already configured Webots preferences to all the user accounts used by the students. On Windows, the Webots preferences are stored in the registry under the `HKEY_CURRENT_USER/SOFTWARE/Cyberbotics` key (so you need to use a tool that copies registry keys across user accounts). On Mac OS X, the Webots preferences are stored in a file under the user home directory at `~/Library/Preferences/com.cyberbotics.Webots8.3.2.plist`. On Linux, the Webots preferences are stored in a file under the user home directory at `~/.config/Cyberbotics/Webots8.3.2.conf`.

1.6.3 Homework

If no IP restriction is set (see above), then the students will be able to use Webots anytime, from any computer, including their own personal computers. In such a case, it's better to use multiple user accounts rather than a single one, to avoid that a few students use all the licenses permanently.

1.6.4 Using Webots without Internet connection

It is possible to use Webots without any Internet connection for a limited amount of time. Users who anticipate they will be away from the Internet can download a license locally on their machine for a specified lease duration. During this period of time, the license is considered to be in use and is not available to other users. The maximum lease duration can be defined by the administrator of the licenses in the "Edit module pack" administration web page. It can be set to "None" to prevent any off-line use of Webots. Otherwise, the maximum lease value can be chosen between 1 hour and 7 days.

In order to download a license locally for off-line use, a user should go to the **Tools** menu of Webots and open the **License Manager...** item. A new window should pop-up to display the available licenses. The user can then choose which licenses to download on his local computer as well as the duration of the lease for these licenses. Warning: this operation cannot be undone. Once transferred locally, the licenses are not available to other computers for the duration of the lease period.

1.7 Translating Webots to your own language

Webots is translated into French, German, Spanish, Chinese and Japanese (and partially into Italian). However, since Webots is always evolving, including new text or changing existing wording, these translations may not always be complete or accurate. As a user of Webots, you are very welcome to help us fix these incomplete or inaccurate translations. This is actually a very easy process which merely consists of editing a UTF-8 XML file, and processing it with a small utility. Your contribution is likely to be integrated into the upcoming releases of Webots, and your name acknowledged in this user guide.

Even if your language doesn't appear in the current Webots Preferences panel, under the **General** tab, you can very easily add it. To proceed with the creation of a new translation or the improvement of an existing one, please follow the instructions located in the `readme.txt` file in the `Webots/resources/translations` folder. Don't forget to send us your translation files!

Chapter 2

Getting Started with Webots

This chapter gives an overview of Webots windows and menus.

2.1 Introduction to Webots

2.1.1 What is Webots?

Webots is a professional mobile robot simulation software package. It offers a rapid prototyping environment, that allows the user to create 3D virtual worlds with physics properties such as mass, joints, friction coefficients, etc. The user can add simple passive objects or active objects called mobile robots. These robots can have different locomotion schemes (wheeled robots, legged robots, or flying robots). Moreover, they may be equipped with a number of sensor and actuator devices, such as distance sensors, drive wheels, cameras, motors, touch sensors, emitters, receivers, etc. Finally, the user can program each robot individually to exhibit the desired behavior. Webots contains a large number of robot models and controller program examples to help users get started.

Webots also contains a number of interfaces to real mobile robots, so that once your simulated robot behaves as expected, you can transfer its control program to a real robot like e-puck, DARwIn-OP, Nao, etc. Adding new interfaces is possible through the related sytem.

2.1.2 What can I do with Webots?

Webots is well suited for research and educational projects related to mobile robotics. Many mobile robotics projects have relied on Webots for years in the following areas:

- Mobile robot prototyping (academic research, the automotive industry, aeronautics, the vacuum cleaner industry, the toy industry, hobbyists, etc.)

- Robot locomotion research (legged, humanoids, quadrupeds robots, etc.)
- Multi-agent research (swarm intelligence, collaborative mobile robots groups, etc.)
- Adaptive behavior research (genetic algorithm, neural networks, AI, etc.).
- Teaching robotics (robotics lectures, C/C++/Java/Python programming lectures, etc.)
- Robot contests (e.g. www.robotstadium.org[1] or www.ratslife.org[2])

2.1.3 What do I need to know to use Webots?

You will need a minimal amount of technical knowledge to develop your own simulations:

- A basic knowledge of the C, C++, Java, Python or Matlab programming language is necessary to program your own robot controllers. However, even if you don't know these languages, you can still program the e-puck and Hemisson robots using a simple graphical programming language called BotStudio.
- If you don't want to use existing robot models provided within Webots and would like to create your own robot models, or add special objects in the simulated environments, you will need a basic knowledge of 3D computer graphics and VRML97 description language. That will allow you to create 3D models in Webots or import them from 3D modelling software.

2.1.4 Webots simulation

A Webots simulation is composed of following items:

1. A Webots *world* file (.wbt) that defines one or several robots and their environment. The .wbt file does sometimes depend on external PROTO files (.proto) and textures.
2. One or several controller programs for the above robots (in C/C++/Java/Python/Matlab).
3. An optional physics plugin that can be used to modify Webots regular physics behavior (in C/C++).

[1] `http://www.robotstadium.org`
[2] `http://www.ratslife.org`

2.1.5 What is a world?

A world, in Webots, is a 3D description of the properties of robots and of their environment. It contains a description of every object: position, orientation, geometry, appearance (like color or brightness), physical properties, type of object, etc. Worlds are organized as hierarchical structures where objects can contain other objects (like in VRML97). For example, a robot can contain two wheels, a distance sensor and a joint which itself contains a camera, etc. A world file doesn't contain the controller code of the robots; it only specifies the name of the controller that is required for each robot. Worlds are saved in `.wbt` files. The `.wbt` files are stored in the `worlds` subdirectory of each Webots project.

2.1.6 What is a controller?

A controller is a computer program that controls a robot specified in a world file. Controllers can be written in any of the programming languages supported by Webots: C, C++, Java, Python or MATLAB™. When a simulation starts, Webots launches the specified controllers, each as a separate process, and it associates the controller processes with the simulated robots. Note that several robots can use the same controller code, however a distinct process will be launched for each robot.

Some programming languages need to be compiled (C and C++) other languages need to be interpreted (Python and MATLAB™) and some need to be both compiled and interpreted (Java). For example, C and C++ controllers are compiled to platform-dependent binary executables (for example `.exe` under Windows). Python and MATLAB™controllers are interpreted by the corresponding run-time systems (which must be installed). Java controller need to be compiled to byte code (`.class` files or `.jar`) and then interpreted by a Java Virtual Machine.

The source files and binary files of each controller are stored together in a controller directory. A controller directory is placed in the `controllers` subdirectory of each Webots project.

2.1.7 What is a Supervisor?

The Supervisor is a privileged type of Robot that can execute operations that can normally only be carried out by a human operator and not by a real robot. The Supervisor is normally associated with a controller program that can also be written in any of the above mentioned programming languages. However in contrast with a regular Robot controller, the Supervisor controller will have access to privileged operations. The privileged operations include simulation control, for example, moving the robots to a random position, making a video capture of the simulation, etc.

2.2 Starting Webots

The first time you start Webots it will open the "Welcome to Webots!" menu with a list of possible starting points.

2.2.1 Linux

Open a terminal and type `webots` to launch Webots.

2.2.2 Mac OS X

Open the directory in which you installed the Webots package and double-click on the Webots icon.

2.2.3 Windows

On Windows 10 and Windows 7, open the **Start** menu, go to the **Program Files** > **Cyberbotics** menu and click on the **Webots 8.3.2** menu item.

On Windows 8, open the **Start** screen, scroll to the screen's right until spotting the Cyberbotics section and click on the **Webots** icon.

2.2.4 Command Line Arguments

Following command line options are available when starting Webots from a Terminal (Linux/-Mac) or a Command Prompt (Windows):

```
SYNOPSIS: webots [options] [worldfile]
OPTIONS:
  --minimize                  minimize Webots window on startup
  --mode=<mode>               choose startup mode (overrides
                              application preferences)
                              argument <mode> must be one of:
                              pause, realtime, run or fast
                              (Webots PRO is required to use:
                              --mode==run or --mode=fast)
  --help                      display this help message and exit
  --sysinfo                   display information of the system and
                              exit
  --version                   display version information and exit
  --uuid                      display the UUID of the computer and
     exit
```

```
--stdout                      redirect the controller stdout to the
                              terminal
--stderr                      redirect the controller stderr to the
                              terminal
--disable-modules-download    skip the check for module updates
--force-modules-download      automatically download module updates
                              (if any) at startup
--start-streaming-server      starts the Webots streaming server
                              (Webots PRO is required)
  ["key[=value];..."]           parameters may be given as an option:
                                  port=1234 :
                                    starts the streaming server
                                    on port 1234
                                  monitorActivity :
                                    prints a dot '.' on stdout every
                                    5 seconds
                                  disableStandardStreamsRedirection :
                                    disables the streaming of the
                                    standard output and error streams
--log-performance="<file path>[,<steps count>]"
                            measure the performance of Webots and
                            log it in the specified <file path>
                            file. <steps count> is an optional
                            integer value that specifies how many
                            steps are analyzed. If '--sysinfo' is
                            also set then the system information are
                            printed in the log file.
```

The optional `worldfile` argument specifies the name of a .wbt file to open. If it is not specified, Webots attempts to open the most recently opened file.

The `--minimize` option is used to minimize (iconize) Webots window on startup. This also skips the splash screen and the eventual Welcome Dialog. This option can be used to avoid cluttering the screen with windows when automatically launching Webots from scripts. Note that Webots PRO does automatically enable the **Fast** mode when `--minimize` is specified.

The `--mode=<mode>` option can be used to start Webots in the specified execution mode. The four possible execution modes are: `pause`, `realtime`, `run` and `fast`; they correspond to the simulation control buttons of Webots' graphical user interface. This option overrides, but does not modify, the startup mode saved in Webots' preferences. For example, type `webots --mode=pause filename.wbt` to start Webots in `pause` mode. Note that `run` and `fast` modes are only available in Webots PRO.

The `--sysinfo` option displays misc information about the current system on the standard output stream and quits Webots.

The `--stdout` and `--stderr` options have the effect of redirecting Webots console output to

the calling terminal or process. For example, this can be used to redirect the controllers output to a file or to pipe it to a shell command. `--stdout` redirects the *stdout* stream of the controllers, while `--stderr` redirects the *stderr* stream. Note that the *stderr* stream may also contain Webots error or warning messages.

The `--disable-modules-download` option disables the download of new modules and therefore prevents the `Webots Update Manager` window from poping up. The `--force-modules-download` will instead force the automatic download of new modules (if available) without asking the user. Both options are mutually exclusive.

The `--start-streaming-server` option starts the Webots streaming server. An option can be given to change the default parameters of the streaming server. This option is a string containing a list of parameter keys and their values separated by semicolons. The supported options are described in table 2.1.

Key	Value example	Description
port	1234	The port on which the streaming server is open

Table 2.1: Streaming server options

For example, the following command will start Webots with the streaming server enabled on the TCP port '1234': `webots --start-streaming-server="port:1234"`

2.3 The User Interface

Webots GUI is composed of four principal windows: the *3D window* that displays and allows to interact with the 3D simulation, the *Scene tree* which is a hierarchical representation of the current world, the *Text editor* that allows to edit source code, and finally, the *Console* that displays both compilation and controller outputs.

The GUI has nine menus: **File, Edit, View, Simulation, Build, Robot, Tools, Wizards** and **Help**.

2.3.1 File Menu

The **File** menu allows you to perform usual file operations: loading, saving, etc.

The **New World** menu item (and button) opens a new world in the simulation window containing only an `ElevationGrid`, displayed as a chessboard of 10 x 10 squares on a surface of 1 m x 1 m.

The **Open World...** menu item (and button) opens a file selection dialog that allows you to choose a `.wbt` file to load.

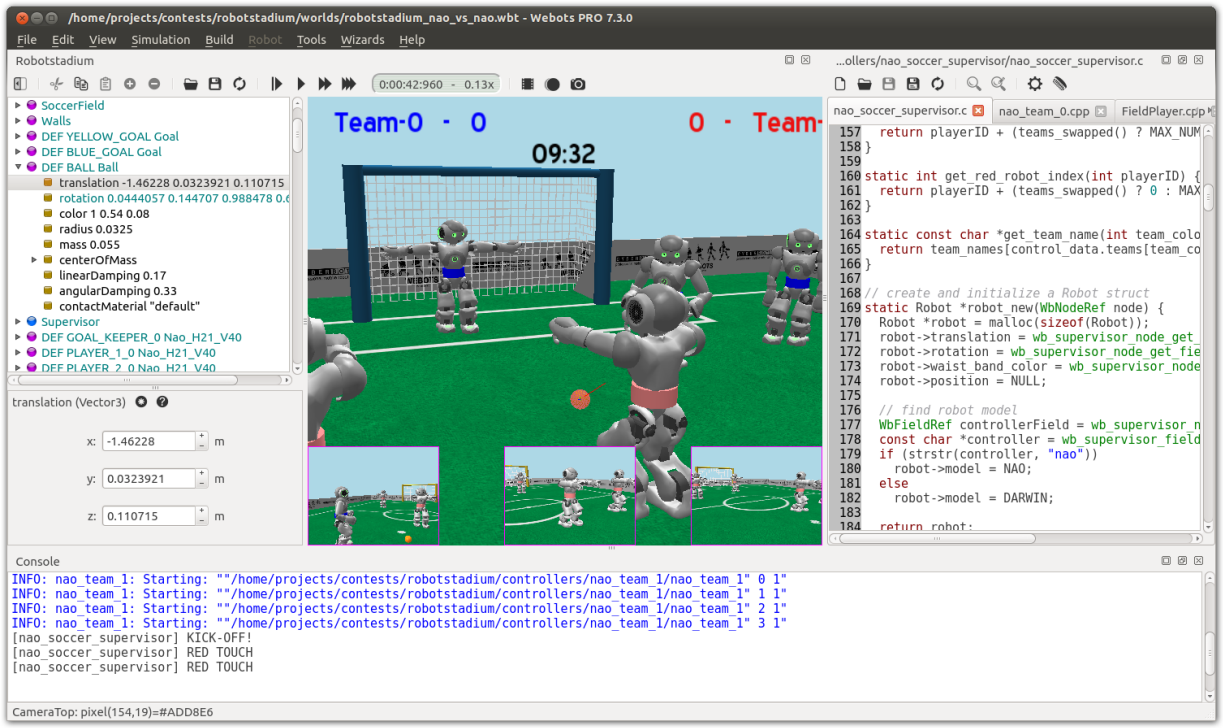


Figure 2.1: Webots GUI

The **Open Recent World** menu item gives the possibility of reopening a `.wbt` file that was opened recently by choosing it from the list displayed in the submenu.

The **Open Sample World** menu item opens a dialog listing all the available sample worlds where it is possible to search for a specific `.wbt` file to load by entering the file name or part of it in the search field.

The **Save World** menu item (and button) saves the current world using the current filename (the filename that appears at the top of the main window). On each **Save** the content of the `.wbt` file is overwritten and no backup copies are created by Webots, therefore you should use this button carefully and eventually do safety copies manually.

The **Save World As...** menu item (and button) saves the current world with a new filename entered by the user. Note that a `.wbt` file should always be saved in a Webots project directory, and in the `worlds` subdirectory, otherwise it will not be possible to reopen the file.

The **Revert World** menu item (and button) reloads the current world from the saved version and restarts the simulation from the beginning.

When opening (or reverting) a world, if the world takes more than 2 seconds to load a window will pop up and show the progression. Using this window it is possible to cancel the loading of the world, in that case, the empty world will be opened instead.

The **New Text File** menu item (and button) opens an empty text file in the text editor.

The **Open Text File...** menu item (and button) opens a file selection dialog that allows you to choose a text file (for example a `.java` file) to load.

The **Save Text File** menu item (and button) saves the current text file.

The **Save Text File As...** menu item (and button) saves the current text file with a new filename entered by the user.

The **Save All Text Files** menu item saves all the opened and unsaved text files.

The **Revert Text File** menu item (and button) reloads the text file from the saved version.

The **Print Preview...** menu item opens a window allowing you to manage the page layout in order to print files from the text editor.

The **Print...** menu item opens a window allowing you to print the current file of the text editor.

The **Import VRML 2.0...** menu item adds VRML97 objects at the end of the scene tree. These objects come from a VRML97 file you must specify. This feature is useful for importing complex shapes that were modeled in a 3D modelling program, then exported to VRML97 (or VRML 2.0). Most 3D modelling software, like 3D Studio Max, Maya, AutoCAD, Pro Engineer, AC3D, or Art Of Illusion, include the VRML97 (or VRML 2.0) export feature. Be aware that Webots cannot import files in VRML 1.0 format. Once imported, these objects appear as `Group`, `Transform` or `Shape` nodes at the bottom of the scene tree. You can then either turn these objects into Webots nodes (like `Solid`, `DifferentialWheels`, etc.) or cut and paste them into the `children` list of existing Webots nodes.

The **Export VRML 2.0...** item allows you to save the currently loaded world as a `.wrl` file, conforming to the VRML97 standard. Such a file can, in turn, be opened with any VRML97 viewer and most 3D modeling software.

The **Take Screenshot...** item allows you to take a screenshot of the current view in Webots. It opens a file dialog to save the current view as a PNG or JPG image.

The **Make Movie...** item allows you to create MPEG movies (Linux and Mac OS X) or AVI movies (Windows). Once the movie recording is started, this item is changed in **Stop Movie...**. During the recording, it is possible to the change the running mode and pause the simulation. However, frames are only captured during Webots steps and not when the simulation is paused.

The **Export HTML5 Model...** item allows you to export the current world as an interactive 3D `.html` file, using the X3DOM web standard, based on WebGL. This is especially useful for publishing Webots-created worlds on the Web. X3DOM is supported in recent versions of Firefox, Chrome, Internet Explorer and Safari on Mac OS X (see details on the X3DOM web site[3]).

With the Chrome browser, in order to be able to open HTML/X3DOM files locally, e.g., not from the Web, you may need to allow Chrome to open local files referred to by the HTML/X3DOM file, e.g., textures. This can be achieved by passing the `--allow-file-access-from-files` *option at Chrome startup. Otherwise textures won't show up in the 3D models.*

The **Make HTML5 Animation...** item allows you to record a simulation as a 3D animation and publish it on a HTML5 web page. The result is similar to a movie with playback controls, except that you can change the viewpoint at any time. Several files are generated: an X3D file containing the 3D scene, a JSON file containing the animation data and a HTML5 file displaying the result using X3DOM and jQuery. Once the animation recording is started, this item is changed to **Stop HTML5 Animation...** and can be used to stop the animation recording.

The **Quit Webots** terminates the current simulation and closes Webots.

2.3.2 Edit Menu

The **Edit** menu provides usual text edition functions to manipulate files opened in the *Text editor*, such as Copy, Paste, Cut, etc.

2.3.3 View Menu

The **View** menu allows to control the viewing in the simulation window.

The **Follow Object** menu item allows to switch between a fixed (static) viewpoint and a viewpoint that follows a mobile object (usually a robot). If you want the viewpoint to follow an object, first you need to select the object with the mouse and then check the **Follow Object** menu item. Note that the **Follow Object** state is saved in the `.wbt` file.

[3] `http://www.x3dom.org`

The **Restore Viewpoint** item restores the viewpoint's position and orientation to their initial settings when the file was loaded or reverted. This feature is handy when you get lost while navigating in the scene, and want to return to the original viewpoint.

The **Fullscreen** item enables and disables displaying the 3D window on the entire screen.

The **Projection** radio button group allows to choose between the **Perspective Projection** (default) and the **Orthographic Projection** mode for Webots simulation window. The *perspective* mode corresponds to a natural projection: in which the farther an object is from the viewer, the smaller it appears in the image. With the *orthographic* projection, the distance from the viewer does not affect how large an object appears. Furthermore, with the *orthographic* mode, lines which are parallel in the model are drawn parallel on the screen, therefore this projection is sometimes useful during the modelling phase. No shadows are rendered in the *orthographic* mode.

The **Rendering** radio button group allows to choose between the **Plain Rendering** (default) and the **Wireframe** modes for Webots simulation window. In *plain rendering* mode, the objects are rendered with their geometrical faces, materials, colors and textures, in the same way they are usually seen by an eye or a camera. In *wireframe rendering* mode, only the segments of the renderable primitives are rendered. This mode can be useful to debug your meshes. If the *wireframe rendering* mode and the **View** > **Optional Rendering** > **Show All Bounding Objects** toggle button are both activated, then only bounding objects are drawn (not the renderable primitives). This can be used to debug a problem with the collision detection.

Finally, the **Optional Rendering** submenu allows to display, or to hide, supplementary information. These rendering are displayed only in the main rendering and hide in the robot camera. They are used to understand better the behavior of the simulation.

The **Show Coordinate System** allows to display, or to hide, the global coordinate system at the bottom right corner of the 3D window as red, green and blue arrows representing the x, y and z axes respectively.

The **Show All Bounding Objects** allows to display, or to hide, all the bounding objects (defined in the *boundingObject* fields of every *Solid* node). Bounding objects are represented by white lines. These lines turn rose when a collision occurs and blue when the solid is idle, i.e., it comes to rest and it doesn't interact with any other active solid.

The **Show Contact Points** allows to display, or to hide, the contact points generated by the collision detection engine. Contact points that do not generate a corresponding contact force are not shown. A contact force is generated only for objects simulated with physics (`Physics` node required). A step is required for taking this operation into account.

The **Show Connector axes** allows to display, or to hide, the connector axes. The rotation alignments are depicted in black while the y and z axes respectively in green and blue.

The **Show Joint axes** allows to display, or to hide, the joint axes. The joint axes are represented by black lines.

The **Show Camera frustums** allows to display, or to hide, the OpenGL culling frustum for every camera in the scene, using a magenta wire frame. The OpenGL culling frustum is a truncated

pyramid corresponding to the field of view of a camera. The back of the pyramid is not represented because the far plane is set to infinity. More information about this concept is available in the OpenGL documentation.

The **Show Distance Sensor rays** allows to display, or to hide, the rays casted by the distance sensor devices. These rays are drawn as red lines (which become green beyond collision points). Their length corresponds to the maximum range of the device.

The **Show Light Sensor rays** allows to display, or to hide, the rays casted by the light sensor devices. These rays are drawn as yellow lines.

The **Show Lights** allows to display, or to hide, the lights (including PointLights and SpotLights). DirectionalLights aren't represented. PointLights and SpotLights are represented by a colored circle surrounded by a flare.

The **Show Pen Painting Rays** allows to display, or to hide, the rays in which the pen devices paint. These rays are drawn as violet lines if painting is enabled, otherwise as gray lines.

The **Show Center Of Mass and Support Polygon** allows to display, or to hide, both the global center of mass of a selected solid (with non NULL `Physics` node) and its support polygon. By support polygon we mean the projection of the convex hull of the solid's contact points on the horizontal plane which contains the lowest one. In addition, the projection of the center of mass in the latter plane is rendered in green if it lies inside the support polygon (static equilibrium), red otherwise. This rendering option can be activated only for solids with no other solid at their top.

If the **Disable selection** option is enabled, it prevents you from changing the selected solid node when clicking on the 3D window. This is particularly useful during the modeling phase, when you want to change the viewpoint without modifying the visible and selected fields in the scene tree.

2.3.4 Simulation Menu

The **Simulation** menu is used to control the execution of the simulation.

The **Pause** menu item (and button) pauses the simulation.

The **Step** menu item (and button) executes one basic time step of simulation. The duration of this step is defined in the `basicTimeStep` field of the `WorldInfo` node, and can be adjusted in the scene tree window to suit your needs.

The **Real-time** menu item (and button) runs the simulation at real-time until it is interrupted by **Pause** or **Step**. In run mode, the 3D display of the scene is refreshed every *n* basic time steps, where *n* is defined in the `displayRefresh` field of the `WorldInfo` node.

The **Run** menu item (and button) is like **Real-time**, except that it runs as fast as possible (Webots PRO only).

The **Fast** menu item (and button) is like **Run**, except that no graphical rendering is performed (Webots PRO only). As the graphical rendering is disabled (black screen) this allows for a faster simulation and therefore this is well suited for cpu-intensive simulations (genetic algorithms, vision, learning, etc.).

2.3.5 Build Menu

The **Build** menu provides the functionality to compile (or cross-compile) controller code. The build menu is described in more details `here`.

2.3.6 Robot Menu

The **Robot** menu provides actions specific to `Robot` nodes. Some actions of this menu are active only when a robot is selected in the 3D window or when there is only one robot in the simulation:

The **Edit Controller** menu item opens the source file of the controller of the selected robot.

The **Camera Devices** submenu contains the list of all the camera devices of the selected robot and lets the user show or hide single camera overlay images by checking or unchecking the corresponding item. Camera overlays differ from the display overlays because of their magenta border. Note that if the **Hide All Camera Overlays** item is checked, then the camera device overlays will not be visible in the 3D view independently from the status of **Camera Devices** menu items. A **Camera Devices** menu item is disabled if the overlay's texture is shown in an external window by double-clicking on it.

The **Display Devices** submenu contains the list of all the display devices of the selected robot and lets the user show or hide single display overlay images by checking or unchecking the corresponding item. Display overlays differ from the camera overlays because of their cyan border. Note that if the **Hide All Display Overlays** item is checked, then the display device overlays will not be visible in the 3D view independently from the status of **Display Devices** menu items. A **Display Devices** menu item is disabled if the overlay's texture is shown in an external window by double-clicking on it.

On the other hand the following items are always active and apply to all the robot in the world:

The **Hide All Camera Overlays** option hides all the camera devices overlays in the 3D view independently from the specific robot's device option set in **Camera Devices** submenu.

The **Hide All Display Overlays** option hides all the display devices overlays in the 3D view independently from the specific robot's device option set in **Display Devices** submenu.

2.3.7 Tools Menu

The **Tools** menu allows you to open various Webots windows.

The **3D View** menu item shows or hides the

The **Scene Tree** menu item opens the

The **Scene Tree** menu item opens the `Scene Tree` window in which you can edit the virtual world. Alternatively it is also possible to double-click on some of the objects in the main window: this automatically opens the Scene Tree with the corresponding object selected.

The **Text Editor** menu item opens the Webots text editor. This editor can be used for editing and compiling controller source code.

The **Console** menu item opens the Webots Console, which is a read-only console that is used to display Webots error messages and controller outputs.

The **Restore Layout** menu item restores the factory layout of the panes of the main window.

The **Clear Console** menu item clears the console.

The **Edit Physics Plugin** menu item opens the source code of the physics plugin in the text editor.

The **License Manager...** item opens the **Webots License Manager** window that allows you to see which license modules are in use and optionally to transfer some license modules to your local computer for off-line use. Please note that the transfer of license modules may be limited by your local license administrator: It may not be possible to transfer some modules to your local computer or only for a limited duration depending on the configuration defined by your local license administrator. Please ask your local license administrator in case of problem.

The **Preferences** item pops up a window described in `this section`.

2.3.8 Wizards Menu

The **Wizards** menu makes it easier to create new projects and new controllers.

The **New Project Directory...** menu item first prompts you to choose a filesystem location and then it creates a project directory. A project directory contains several subdirectories that are used to store the files related to a particular Webots project, i.e. world files, controller files, data files, plugins, etc. Webots remembers the current project directory and automatically opens and saves any type of file from the corresponding subdirectory of the current project directory.

The **New Robot Controller...** menu item allows you to create a new controller program. You will first be prompted to choose between a C, C++, Java, Python or MATLAB™controller. Then, Webots will ask you to enter the name of your controller and finally it will create all the necessary files (including a template source code file) in your current project directory.

The **New Physics Plugin...** menu item will let you create a new physics plugin for your project. Webots asks you to choose a programming language (C or C++) and a name for the new physics plugin. Then it creates a directory, a template source code file and a Makefile in your current project.

2.3.9 Help menu

In the **Help** menu, the **About...** item opens the `About...` window that displays the license information.

The **Webots Guided Tour...** menu item starts a guided tour that demonstrates Webots capabilies through a series of examples.

The **OpenGL Information...** menu item gives you information about your current OpenGL hardware and driver. It can be used to diagnose rendering problems.

The remaining menu items bring up various information as indicated, in the form of HTML pages, PDF documents, etc.

2.3.10 Main toolbar

The main toolbar contains items for editing the world and the speedometer (see subsection subsection 2.3.11), other than shortcuts to items of the **File**, **Simulation** and **View** menus. Edit actions always apply on the selected object, that is highlighted both in the 3D window and in the Scene Tree.

Hide/Show Scene Tree: shows or hides the Scene Tree and resizes the 3D window consequently.

Cut: Cuts the selected object.

Copy: Copies the selected object.

Paste: Pastes the copied or cut object.

Note that the first three nodes of the Scene Tree (`WorldInfo`, `Viewpoint`, and `Background`) cannot be cut, copied or pasted. One single instance of each of these nodes must be present in every Webots world, and in that precise order.

Add: Adds a node or an object. For nodes, this triggers a dialog that will let you choose a node type from a list. The new node is created with default values that can be modified afterwards. You can only insert a node suitable for the corresponding field. The dialog also gives the possibility to load a previously exported node by clicking on the **Import...** button. Further information about how to export a node are available here.

Delete: Deletes the selected object.

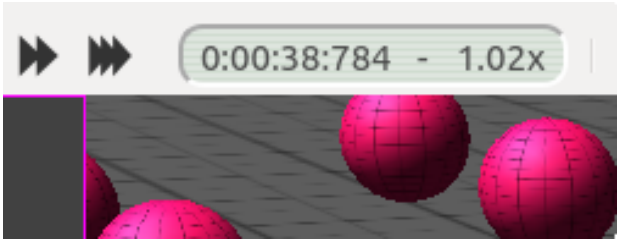


Figure 2.2: Speedometer

2.3.11 Speedometer and Virtual Time

A speedometer (see figure 2.2) indicates the speed of the simulation on your computer. It is displayed on the main toolbar, and indicates how fast the simulation runs compared to real time. In other words, it represents the speed of the virtual time. If the value of the speedometer is 2, it means that your computer simulation is running twice as fast as the corresponding real robots would. This information is valid both in **Run** mode and **Fast** mode.

To the left of the speedometer, the *virtual time* is displayed using following format:

H:MM:SS:MMM

where *H* is the number of hours (may be several digits), *MM* is the number of minutes, *SS* is the number of seconds, and *MMM* is the number of milliseconds (see figure 2.2). If the speedometer value is greater than one, the virtual time is progressing faster than real time.

The basic time step for simulation can be set in the `basicTimeStep` field of the `WorldInfo` node in the scene tree window. It is expressed in virtual time milliseconds. The value of this time step defines the length of the time step executed during the **Step** mode. This step is multiplied by the `displayRefresh` field of the same `WorldInfo` node to define how frequently the display is refreshed.

2.4 The 3D Window

2.4.1 Selecting an object

A single mouse click allows to select a solid object. The bounding object of a selected solid is represented by white lines. These lines turn rose if the solid is colliding with another one and blue when the solid is idle, i.e., it comes to rest and it doesn't interact with any other active solid. Selecting a robot enables the **Show Robot Window** item in the **Tools** menu. Double-clicking on a solid object opens the Robot Window and if it was closed, the Scene Tree.

If an object has a solid subpart, then it is also possible to select only this subpart by clicking on it once the whole object is already selected, or by clicking on it while holding down the Alt key. Linux users should also hold down the Control key (Ctrl) together with the Alt key.

2.4.2 Navigation in the scene

Dragging the mouse while pressing a mouse button moves the camera of the 3D window.

- *Camera rotation*: In the 3D window, press the left button and drag the mouse to select an object and rotate the viewpoint about it. If no object is selected, the camera rotates about the origin of the world coordinate system.

- *Camera translation*: In the 3D window, press the right button and drag the mouse to translate the camera with the mouse motion.

- *Zooming / Camera rotation*: In the 3D window, press both left and right mouse buttons simultaneously (or just the middle button) and drag the mouse vertically, to zoom in and out. Dragging the mouse horizontally will rotate the camera about the viewing axis. Alternatively, the mouse wheel alone can also be used for zooming.

If you are a Mac user with a single button mouse, hold the Alt key and press the mouse button to translate the camera according to the mouse motion. Hold the control key (Ctrl) down and press the mouse button to zoom / rotate the camera with the mouse motion.

2.4.3 Moving a solid object

Currently Webots provides two different ways to move solid objects: axis-aligned handles and keyboard shortcuts.

Axis-aligned handles

When a solid object is selected, some arrow-shaped handles appear in the 3D window (see figure 2.3). These handles can be used to translate and rotate the object along the corresponding axis. For moving the object you can simply click on the handle and drag it to the desired position. A label will show the currect relative translation or rotation during the movement, as shown in figure 2.4.

If the Control key (Ctrl), the handles for resizing the solid object will be displayed instead of translation and rotation handles. These resize handles can also be enabled from the Field Editor.

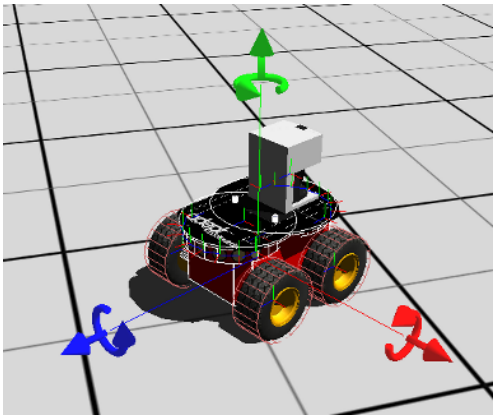


Figure 2.3: Axis-aligned handles to move solid objects

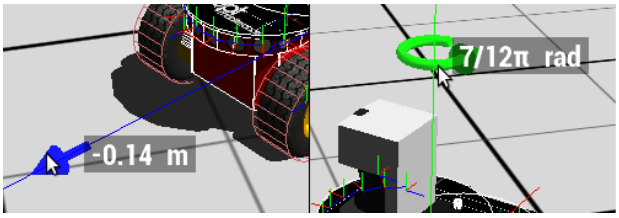


Figure 2.4: Labels displaying relative translation and rotation when moving objects with handles

Translation using keyboard shurtcuts

- *Translation*: To move an object parallel to the ground: hold down the shift key, press the left mouse button and drag.
- *Lift*: To raise or lower and object: hold down the Shift key, press both left and right mouse buttons (or the middle button) and drag. Alternatively, the mouse wheel combined with the Shift key can also be used.

If you are a Mac user with a single button mouse, hold the Shift key and the Control key (Ctrl) down and press the mouse button to rotate the selected object according to mouse motion. Hold the Shift key and the Command key (key with Apple symbol) down and press the mouse button to lift the selected object according to mouse motion.

2.4.4 Applying a force to a solid object with physics

To apply a force to an object, place the mouse pointer where the force will apply, hold down the Alt key and left mouse button together while dragging the mouse. Linux users should also

hold down the Control key (Ctrl) together with the Alt key. This way your are drawing a 3D-vector whose end is located in the plane parallel to the view which passes through the point of application. The intensity of the applied force is directly proportional to the cube of the length of this vector.

2.4.5 Applying a torque to a solid object with physics

To apply a torque to an object, place the mouse pointer on it, hold down the Alt key and right mouse button together while dragging the mouse. Linux users should also hold down the Control key (Ctrl) together with the Alt key. Also, Mac OS X users with a one-button mouse should hold down the Control key (Ctrl) to emulate the right mouse button. This way your are drawing a 3D-vector with origin the center of mass and whose end is located in the plane parallel to the view which passes through this center. The object is prompted to turn around the vector direction, the intensity of the applied torque being directly proportional to the product of the mass by the length of the 3D-vector.

In pause mode, you can simultaneously add a force and a torque to the same selected solid. Camera rotation can be useful when checking wether your force / torque vector has the desired direction.

2.4.6 Moving and resizing Overlays

By default for each Camera and Display device, an overlay showing the recorded or displayed image is visible in the 3D view. The device type is indicated by the border color: magenta for Camera devices and cyan for Display devices, see figure 2.5. This overlay can be moved to the desired position on the view by clicking on it and dragging the mouse. In order to resize the overlay the user has to click on the icon located at the bottom right corner and drag the mouse, during this action the original not scaled image size will be indicated using darker areas, as depicted in figure 2.6 Additionally a close button is available on the top right corner to hide the overlay. Once the robot is selected, it is also possible to show or hide the overlay images from the **Camera Devices** and **Display Devices** items in **Robot** menu.

2.4.7 Show Camera and Display images in separate window

Overlay images can also be displayed outside the 3D window, see figure 2.7. When double-clicking with the left mouse button on the overlay, a new external window displaying the device image is created and the overlay in the 3D window is disabled. It is possible to restore the 3D window overlay simply by closing the window.

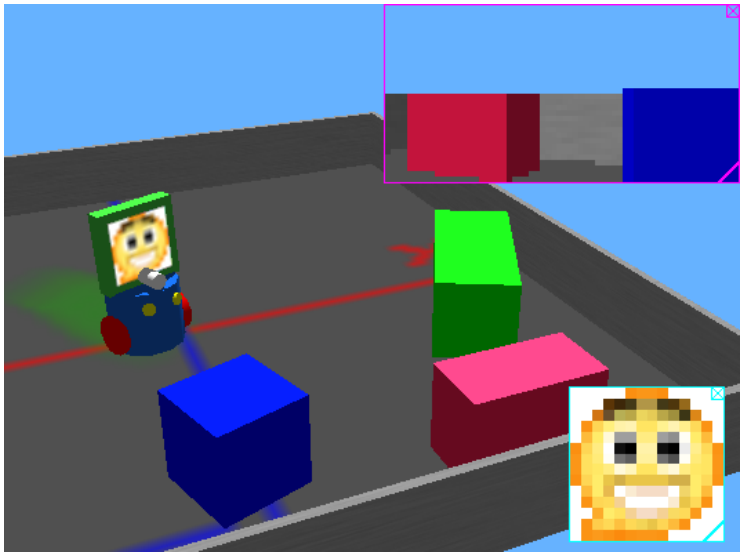


Figure 2.5: Camera and Display overlays

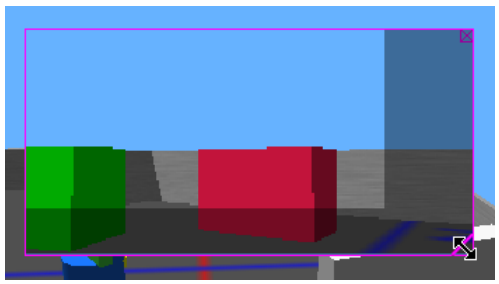


Figure 2.6: Camera overlay resizing

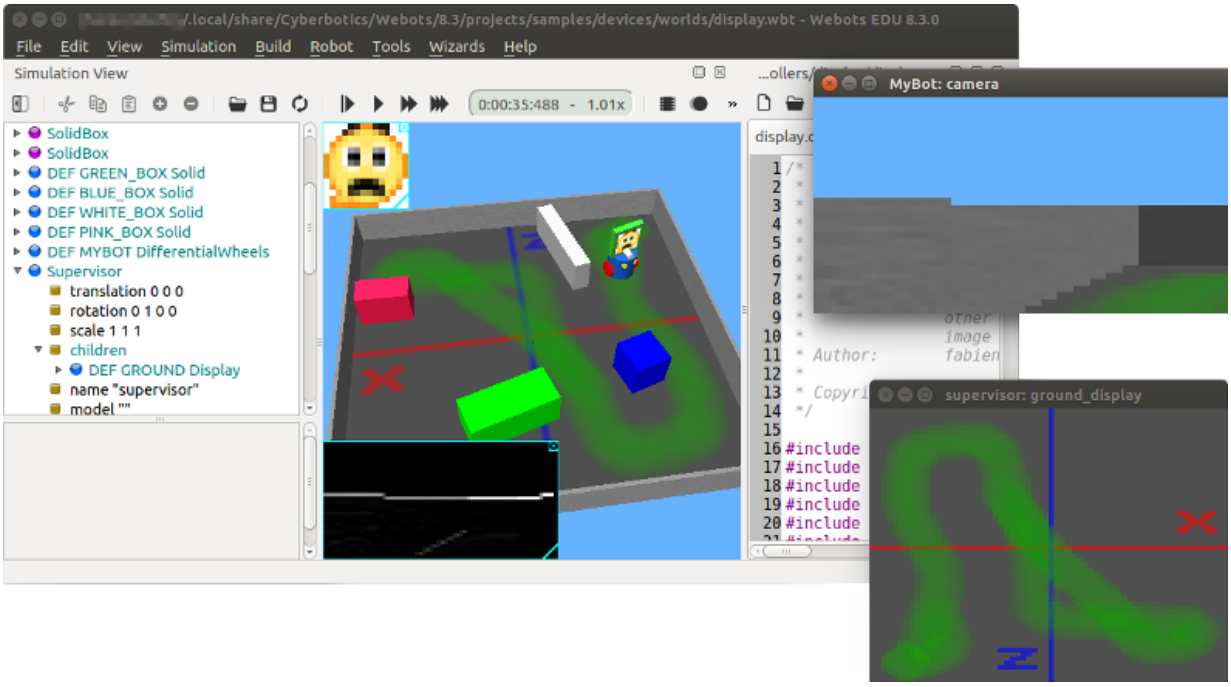


Figure 2.7: Camera and Display image window

2.5 The Scene Tree

As seen in the previous section, to access to the Scene Tree Window you can either choose **Scene Tree** in the **Tools** menu, or press the **Show Scene Tree** button in the main toolbar. The scene tree contains the information that describes a simulated world, including robots and environment, and its graphical representation. The scene tree of Webots is structured like a VRML97 file. It is composed of a list of nodes, each containing fields. Fields can contain values (text strings, numerical values) or other nodes.

This section describes the user interface of the Scene Tree, gives an overview of the VRML97 nodes and Webots nodes.

2.5.1 Field Editor

Nodes can be expanded with a double-click. When a field is selected, its value can be edited at the bottom of the Scene Tree. All changes will be immediately reflected in the 3D window. The following buttons are available int the field editor section:

Reset: Resets a field to its default value.

Help: Context sensitive help for the currently selected node.

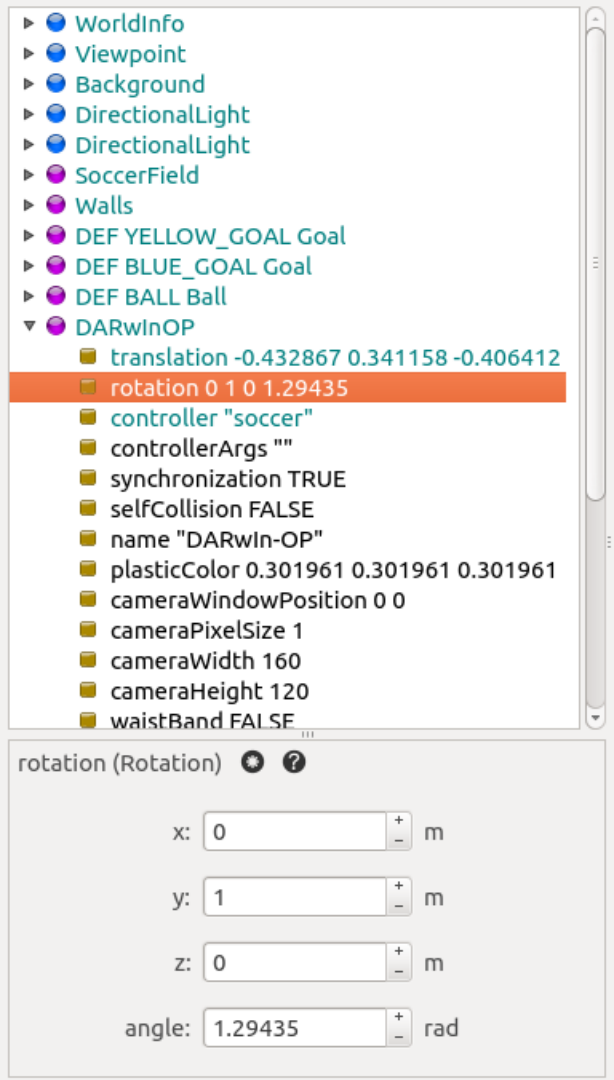


Figure 2.8: Scene Tree Window

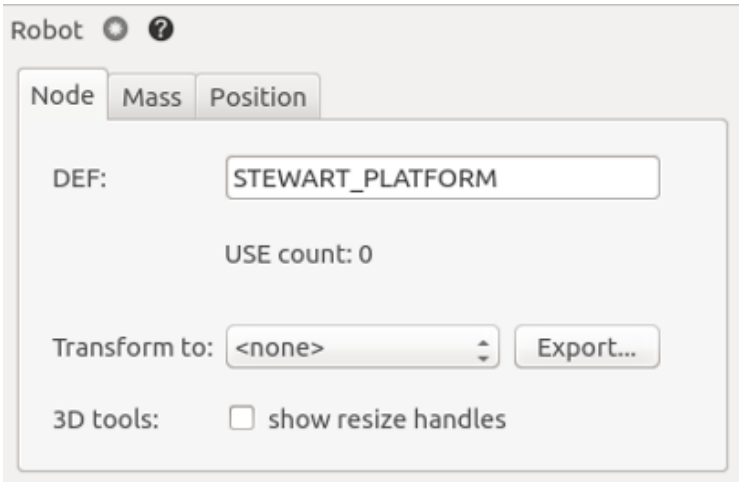


Figure 2.9: Webots node editor

Additionally, when a node is selected, other actions are available as shown in figure 2.9:

Tranform to: Allow to change the type of the selected node by chosing the target type from a given list of suitable types. This action is not available for all node's types.

Export...: Exports nodes that can then be imported in other worlds.

Source: Displayed only when a PROTO node is selected, opens the corresponding PROTO definition file in the text editor.

Result: Displayed only when a procedural PROTO node is selected, opens the PROTO definition file generated by the template engine in the text editor.

Show resize handles: Displays the handles for resizing and scaling the selected node from the 3D Window. This option is disabled for PROTO nodes and only displayed for Geometry nodes and nodes derived from Transform.

We recommend to use the Scene Tree to write Webots world files. However, because the nodes and fields are stored in a human readable form, it is also possible to edit world files with a regular text editor. Some search and replace operations may actually be easier that way. Please refer to Webots Reference Manual for more info on the available nodes and the world file format.

2.6 Preferences

The Webots preferences can be modified by a dialog box which can be open from the **Webots** > **Preferences** menu item on Mac, and from the **Tools** > **Preferences** menu item on the other operating systems.

The dialog box is separated into tabs. Each of the following subsection corresponds to one of this tab.

2.6.1 General

The **General** tab contains misc preferences about the application.

- The **Language** option allows you to choose the language of Webots user interface (restart needed).
- The **Startup mode** allows you to choose the state of the simulation when Webots is started (pause, realtime, run, fast; see the **Simulation** menu).
- The **Editor font** defines the font to be used in Webots text editor and in the Console. It is recommended to select a fixed width font for better source code display. The default value of this preference is "Consolas,10" on Windows, "Courier,14" on Mac and "Monospace" on linux.
- The **Number of threads** defines how many threads can be created by Webots at maximum. The recommended value matches with the number of logical cores of the computer processor. It may be interesting to reduce this value in some specific cases, for example when another process requires intensively other cores. For now this value affects only the physical engine speed, and the controller compilation speed. Note that this is the maximum number of threads allowed, but the actual number of threads used is the one defined in the `optimalThreadCount` field of the `WorldInfo` node.

2.6.2 OpenGL

The **OpenGL** tab contains preferences about setting the 3D rendering abilities. The initial parameters of these settings may vary from one computer to another depending on the GPU OpenGL abilities.

- The **RTT preferred mode** option allows you to modify the method used to create the Camera device images. The methods are sorted from the most efficient one to the less efficient one.
- The **Disable shadows** option allows you to disable completely the shadows in the 3D view and in the Camera rendering, whatever the values of the *Light.castShadows* fields.

  The global performances can be improved by disabling this feature, but on the other hand the rendering is more difficult to understand, and less pretty.
- The **Disable shader** option allows you to use the regular OpenGL shading model, instead of a custom shading. This custom shading model computes the light effects on the 3D objects per pixel instead of per vertex, resulting in a much smoother rendering. It may be interesting to disbale this feature on old GPU if the shaders are not well supported.

- The **Disable camera anti-aliasing** option allows you to bypass all the *Camera.antialiasing* fields and to disable this feature. We observed that some hardware doesn't support the OpenGL feature about anti-aliasing when rendering into a texture (RTT).

2.7 Citing Webots

If you write a scientific paper or describe your project involving Webots on a web page, we will greatly appreciate if you can add a reference to Webots. For example by explicitly mentioning Cyberbotics' web site or by referencing a journal paper that describes Webots. To make this simpler, we provide here some citation examples, including BibTex entries that you can use in your own documents.

2.7.1 Citing Cyberbotics' web site

This project uses Webots[4]*, a commercial mobile robot simulation software developed by Cyberbotics Ltd.*

This project uses Webots (http://www.cyberbotics.com), a commercial mobile robot simulation software developed by Cyberbotics Ltd.

The BibTex reference entry may look odd, as it is very different from a standard paper citation and we want the specified fields to appear in the normal plain citation mode of LaTeX.

```
@MISC{Webots,
  AUTHOR = {Webots},
  TITLE  = {http://www.cyberbotics.com},
  NOTE   = {Commercial Mobile Robot Simulation Software},
  EDITOR = {Cyberbotics Ltd.},
  URL    = {http://www.cyberbotics.com}
}
```

Once compiled with LaTeX, it should display as follows:

References

[1] Webots. http://www.cyberbotics.com. Commercial Mobile Robot Simulation Software.

2.7.2 Citing a reference journal paper about Webots

A reference paper was published in the International Journal of Advanced Robotics Systems. Here is the BibTex entry:

[4] http://www.cyberbotics.com

```
  @ARTICLE{Webots04,
  AUTHOR  = {Michel, O.},
  TITLE   = {Webots: Professional Mobile Robot Simulation},
  JOURNAL = {Journal of Advanced Robotics Systems},
  YEAR    = {2004},
  VOLUME  = {1},
  NUMBER  = {1},
  PAGES   = {39--42},
  URL     = {http://www.ars-journal.com/International-Journal-of-
             Advanced-Robotic-Systems/Volume-1/39-42.pdf}
}
```

Chapter 3

Sample Webots Applications

This chapter gives an overview of sample worlds provided with the Webots package. The examples world can be tried easily; the `.wbt` files are located in various `worlds` directories of the `WEBOTS_MODULES_PATH/projects` directory and can be directly opened from Webots using the **Open Sample World** item in **File** menu. The controller code is located in the corresponding `controllers` directory. This chapter provides each example a with short abstract only. More detailed explanations can be found in the source code.

3.1 Samples

This section provides a list of interesting worlds that broadly illustrate Webots capabilities. Several of these examples have stemmed from research or teaching projects. You will find the corresponding `.wbt` files in the `WEBOTS_MODULES_PATH/projects/samples/demos/worlds` directory, and their controller source code in the `WEBOTS_MODULES_PATH/projects/samples/demos/controllers` directory. For each demo, the world file and its corresponding controller have the same name.

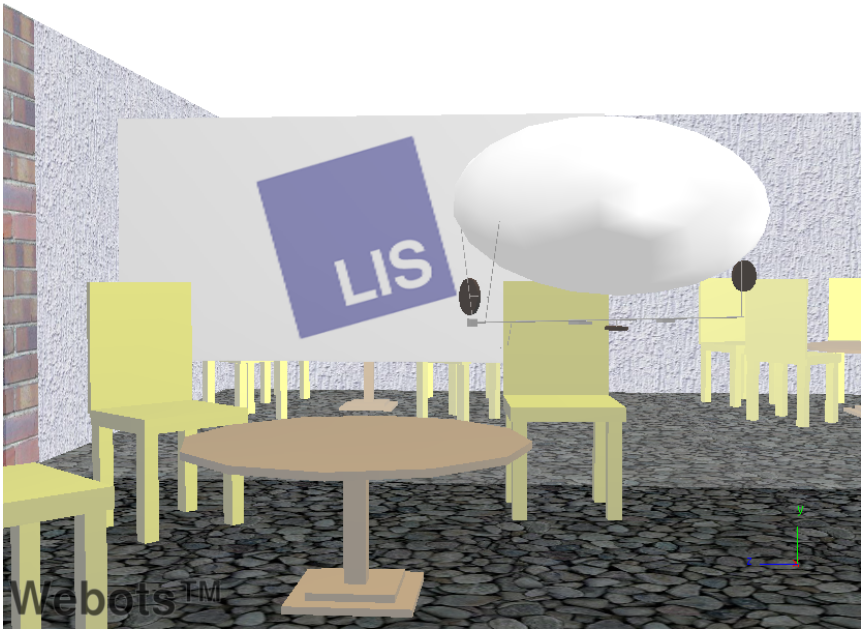


Figure 3.1: blimp_lis.wbt

3.1.1 blimp_lis.wbt

Keywords: *Flying robot, physics plugin, keyboard, joystick*

This is an example of the flying blimp robot developed at the Laboratory of Intelligent Systems (LIS) at EPFL. You can use your keyboard, or a joystick to control the blimp's motion across the room. Use the up, down, right, left, page up, page down and space (reset) keys. Various `Transform` and `IndexedFaceSet` nodes are used to model the room using textures and transparency. A *physics plugin* is used to add thrust and other forces to the simulation.

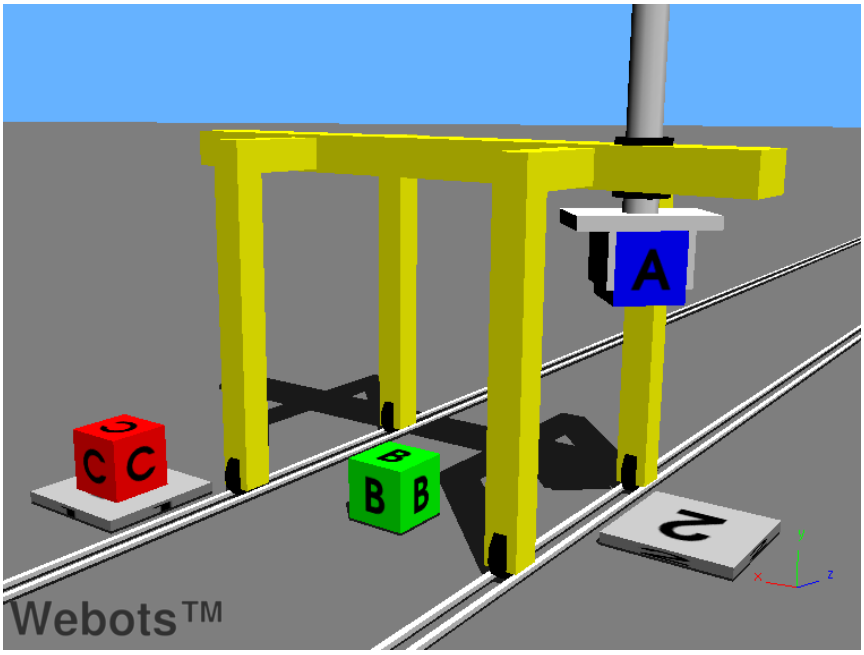


Figure 3.2: gantry.wbt

3.1.2 gantry.wbt

Keywords: *Gantry robot, gripper, Hanoi towers, linear motors, recursive algorithm*

In this example, a gantry robot plays ”Towers of Hanoi” by stacking three colored boxes. The gantry robot is modeled using a combination of `LinearMotor` and `RotationalMotor` devices. A recursive algorithm is used to solve the Hanoi Towers problem.

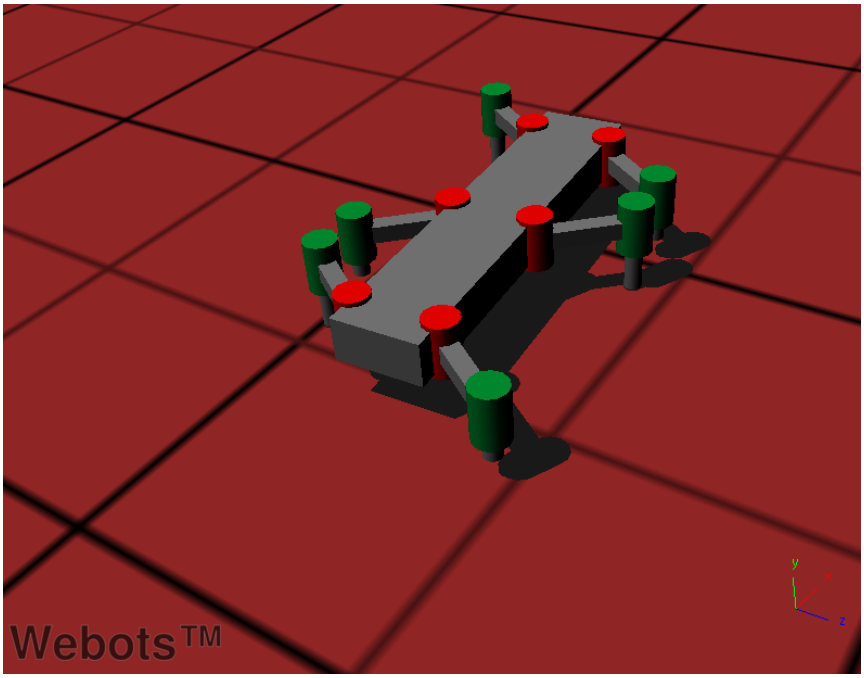


Figure 3.3: hexapod.wbt

3.1.3 hexapod.wbt

Keywords: *Legged robot, alternating tripod gait, linear motor*

In this example, an insect-shaped robot is made of a combination of `LinearMotor` and `RotationalMotor` devices. The robot moves using an alternating tripod gait.

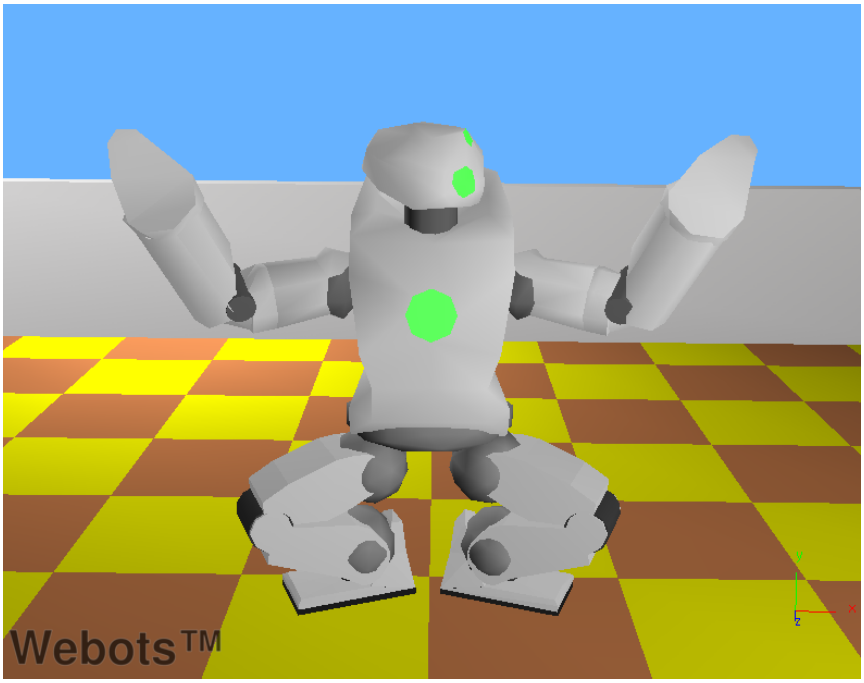


Figure 3.4: humanoid.wbt

3.1.4 humanoid.wbt

Keywords: *Humanoid, QRIO robot*

In this example, a humanoid robot performs endless gymnastic movements.

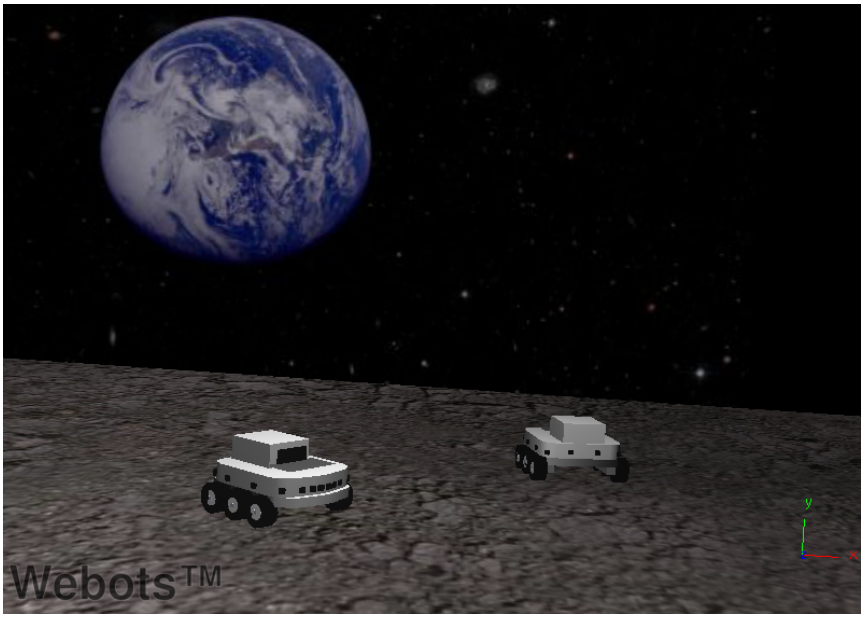


Figure 3.5: moon.wbt

3.1.5 moon.wbt

Keywords: *DifferentialWheels, Koala, keyboard, texture*

In this example, two Koala robots (K-Team) circle on a moon-like surface. You can modify their trajectories with the arrow keys on your keyboard. The moon-like scenery is made of `IndexedFaceSet` nodes. Both robots use the same controller code.

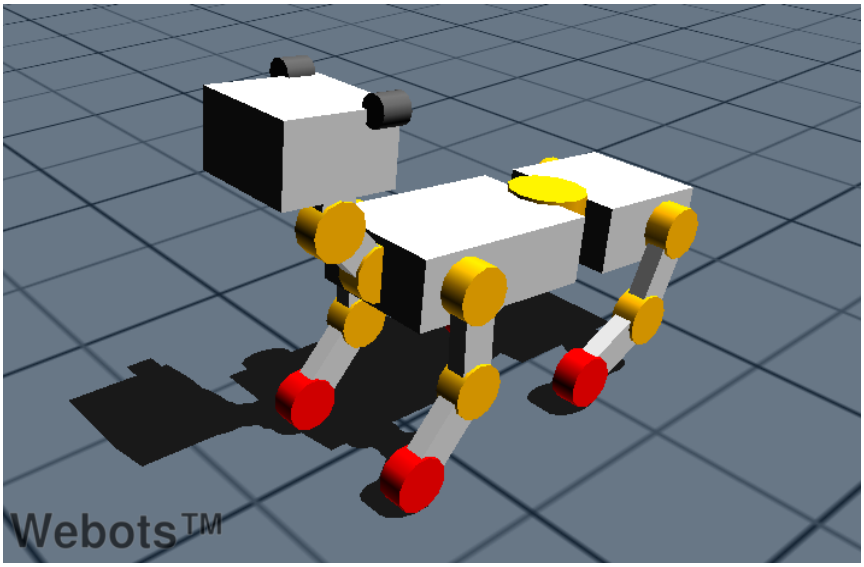


Figure 3.6: ghostdog.wbt

3.1.6 ghostdog.wbt

Keywords: *Quadruped, legged robot, dog robot, passive joint, spring and damper*

This example shows a galloping quadruped robot made of active hip joints and passive knee joints (using spring and dampers). The keyboard can be used to control the robot's direction and to change the amplitude of the galloping motion. Each knee is built of two embedded HingeJoint nodes, one active and one passive, sharing the same rotation axis. The passive HingeJoint simulates the spring and damping. The active HingeJoint is not actuated in this demo but it could be used for controlling the knee joints.

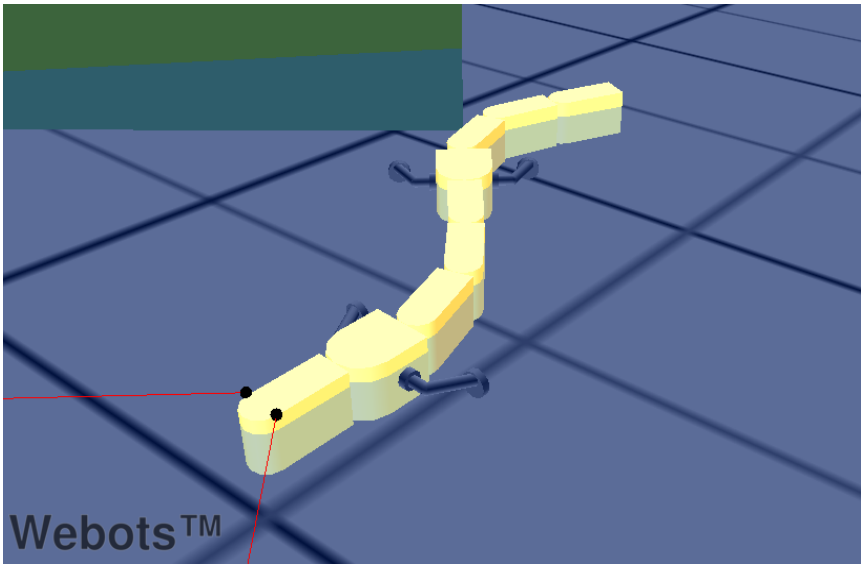


Figure 3.7: salamander.wbt

3.1.7 salamander.wbt

Keywords: *Salamander robot, swimming robot, amphibious robot, legged robot, physics plugin, buoyancy*

A salamander-shaped robot walks down a slope and reaches a pool where it starts to swim. The controller uses two different types of locomotion: it walks on the ground and swims in the water. This demo simulates propulsive forces caused by the undulations of the body and the resistance caused by the robot's shape. In addition, the buoyancy of the robot's body is also simulated using Archimedes' principle.

Figure 3.8: soccer.wbt

3.1.8 soccer.wbt

Keywords: *Soccer, Supervisor, DifferentialWheels, label*

In this example, two teams of simple `DifferentialWheels` robots play soccer. A `Supervisor` is used as the referee; it counts the goals and displays the current score and the remaining time in the 3D view. This example shows how a `Supervisor` can be used to read and change the position of objects.

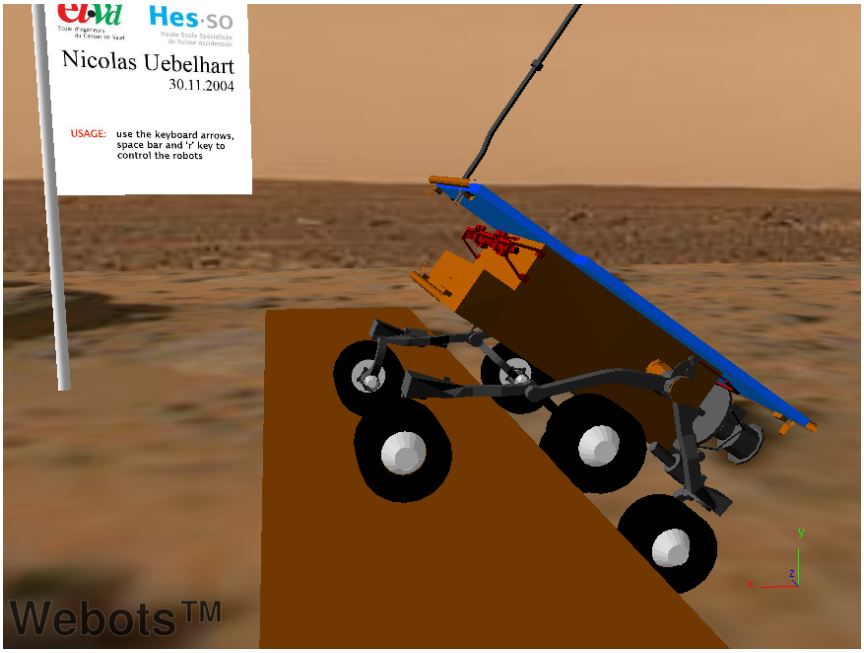


Figure 3.9: sojourner.wbt

3.1.9 sojourner.wbt

Keywords: *Sojourner, Passive joint, planetary exploration robot, keyboard, IndexedFaceSet*

This is a realistic model of the ”Sojourner” Mars exploration robot (NASA). A large obstacle is placed in front of the robot so that it is possible to observe how the robot manages to climb over it. The keyboard can be used to control the robot’s motion.

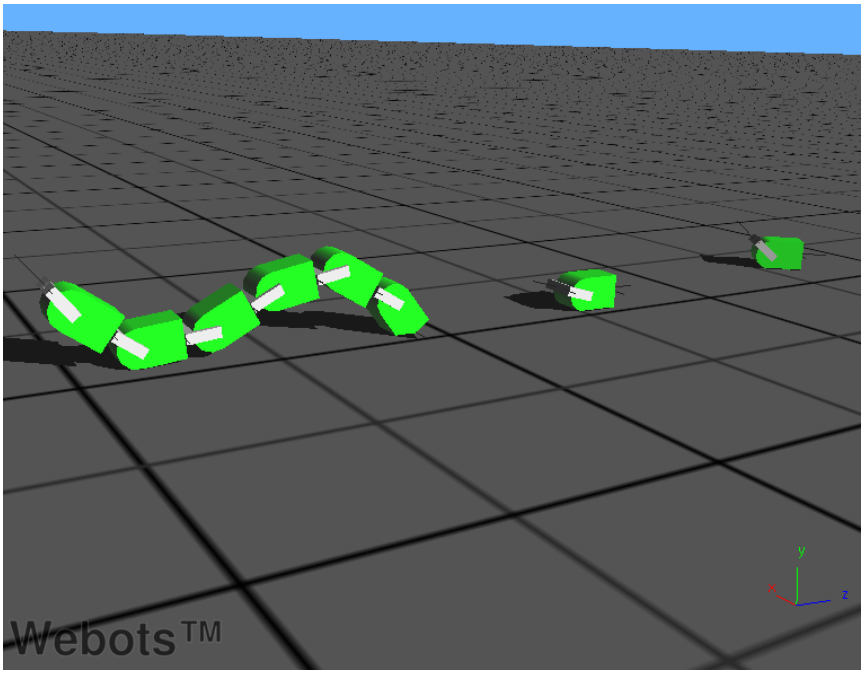


Figure 3.10: yamor.wbt

3.1.10 yamor.wbt

Keywords: *Connector, modular robots, self-reconfiguring robot*

In this example, eight ”Yamor” robot modules attach and detach to and from each other using `Connector` devices. Connector devices are used to simulate the mechanical connections of docking systems. In this example, the robot modules go through a sequence of loops and worm-like configurations while changing their mode of locomotion. All modules use the same controller code, but their actual module behaviour is chosen according to the name of the module.

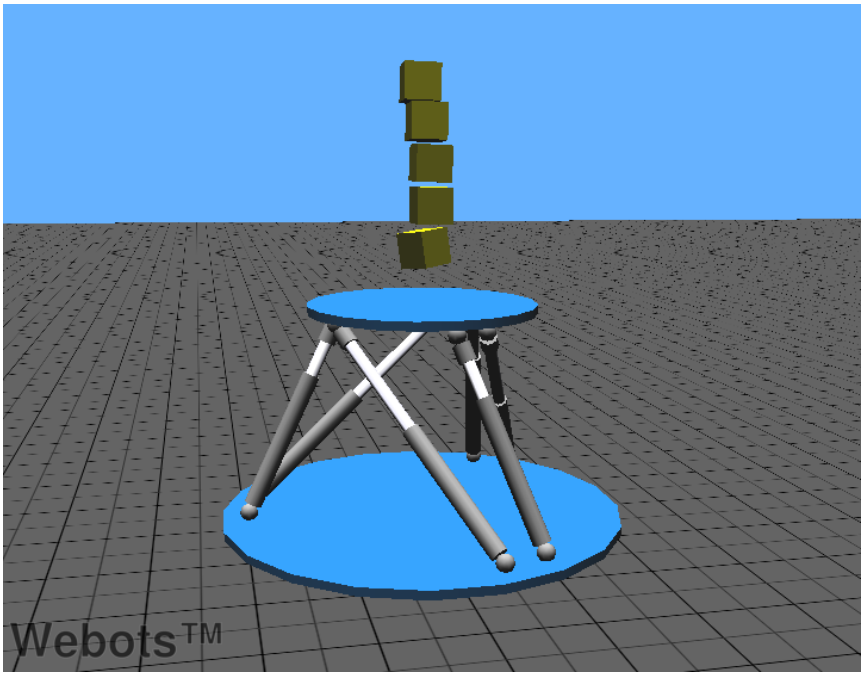


Figure 3.11: stewart_platform.wbt

3.1.11 stewart_platform.wbt

Keywords: *Stewart platform, linear motion, physics plugin, ball joint, universal joint*

This is an example of a *Stewart platform*. A Stewart platform is a kind of parallel manipulator that uses an octahedral assembly of linear actuators. It has six degrees of freedom (x, y, z, pitch, roll, and yaw). In this example, the Stewart platform is loaded with a few stacked boxes, then the platform moves and the boxes stumble apart. This simulation attaches both ends of the linear actuators (hydraulic pistons) to the lower and the upper parts of the Stewart platform.

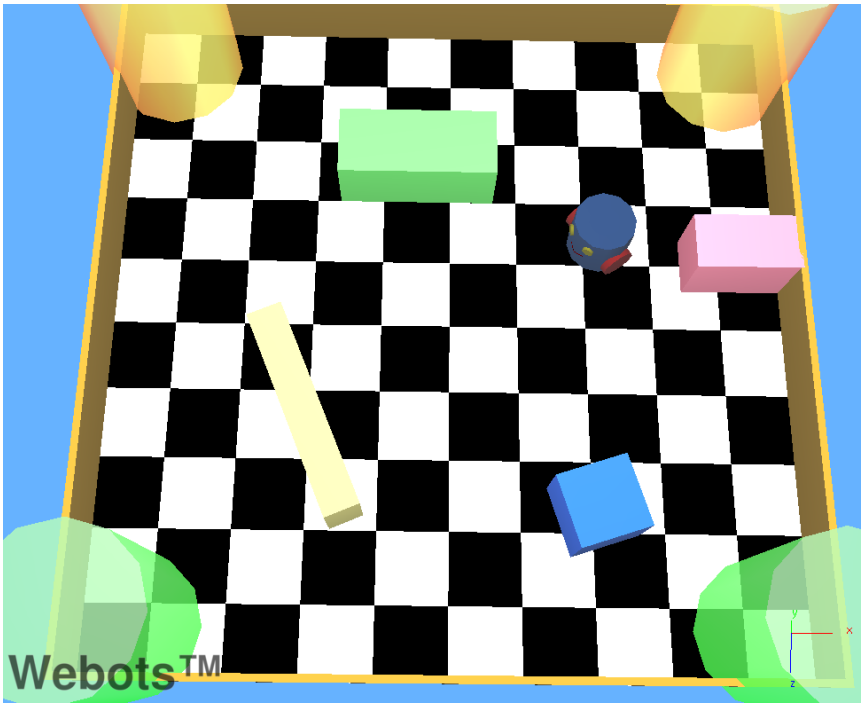


Figure 3.12: battery.wbt

3.2 Webots Devices

This section provides a simple example for each Webots device. The world files are located in the `WEBOTS_MODULES_PATH/projects/samples/devices/worlds` directory, and their controllers in the `WEBOTS_MODULES_PATH/projects/samples/devices/controllers` directory. The world files and the corresponding controller are named according to the device they exemplify.

3.2.1 battery.wbt

Keywords: *Battery, Charger, DifferentialWheels*

In this example, a robot moves in a closed arena. The energy consumed by the wheel motors slowly discharges the robot's battery. When the battery level reaches zero, the robot is powered off. In order to remain powered, the robot must recharge its battery at energy chargers. Chargers are represented by the semi-transparent colored cylinders in the four corners of the arena. Only a full charger can recharge the robot's battery. The color of a charger changes with its energy level: it is red when completely empty and green when completely full.

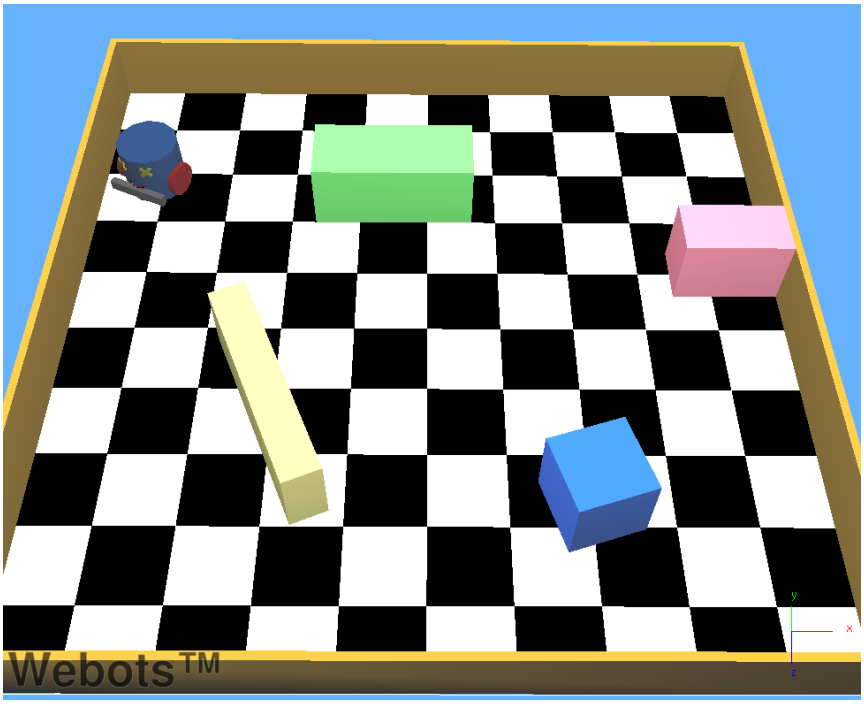


Figure 3.13: bumper.wbt

3.2.2 bumper.wbt

Keywords: *TouchSensor, bumper, DifferentialWheels*

In this example, a robot moves in a closed arena filled with obstacles. Its ”bumper” `TouchSensor` is used to detect collisions. Each time a collision is detected, the robot moves back and turns a bit.

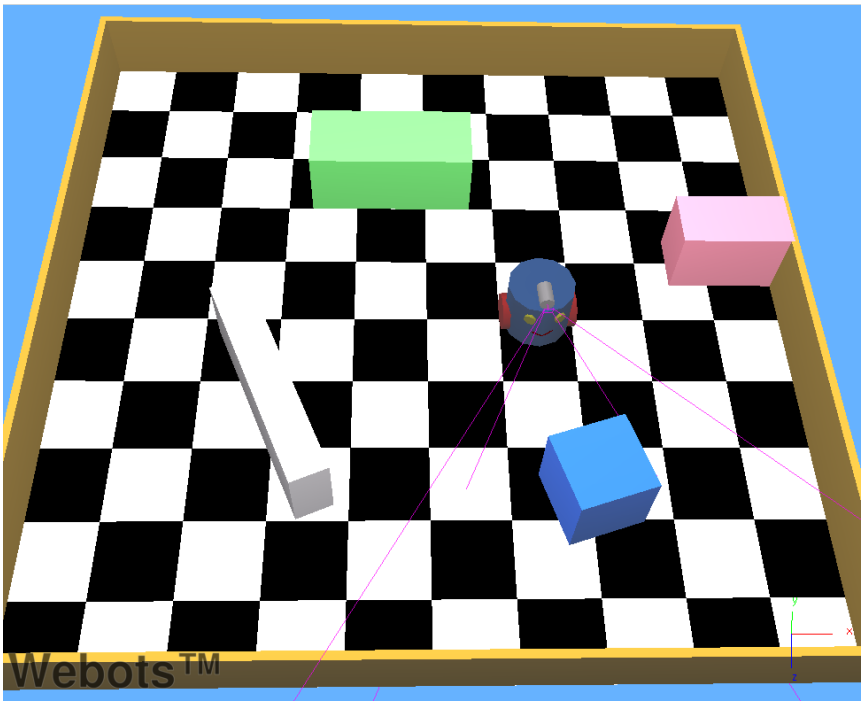


Figure 3.14: camera.wbt

3.2.3 camera.wbt

Keywords: *Camera, image processing, DifferentialWheels*

In this example, a robot uses a camera to detect colored objects. The robot analyses the RGB color level of each pixel of the camera images. It turns and stops for a few seconds when it has detected something. It also prints a message in the Console explaining the type of object it has detected. You can move the robot to different parts of the arena (using the mouse) to see what it is able to detect.

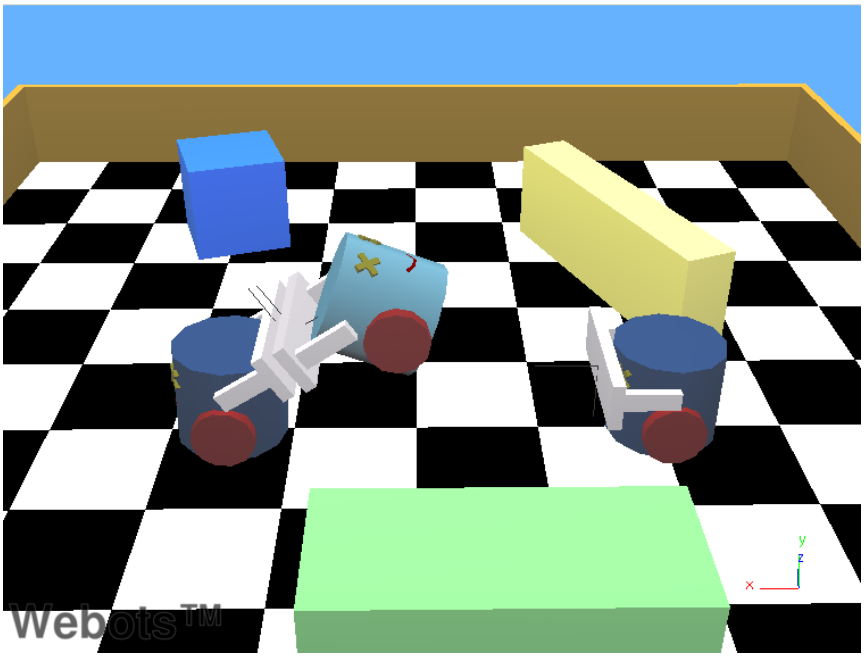


Figure 3.15: connector.wbt

3.2.4 connector.wbt

Keywords: *Connector, RotationalMotor, IndexedLineSet, USE, DEF, DifferentialWheels*

In this example, a light robot (light blue) is lifted over two heavier robots (dark blue). All three robots are equipped with a `Connector` placed at the tip of a moveable handle (`HingeJoint`). An `IndexedLineSet` is added to every `Connector` in order to show the axes. When the simulation starts, the light robot approaches the first heavy robot and their connectors dock to each other. Then both robots rotate their handles simultaneously, and hence the light robot gets passed over the heavy one. Then the light robot gets passed over another time the second heavy robot and so on ... All the robots in this simulation use the same controller; the different behaviors are selected according to the robot's name.

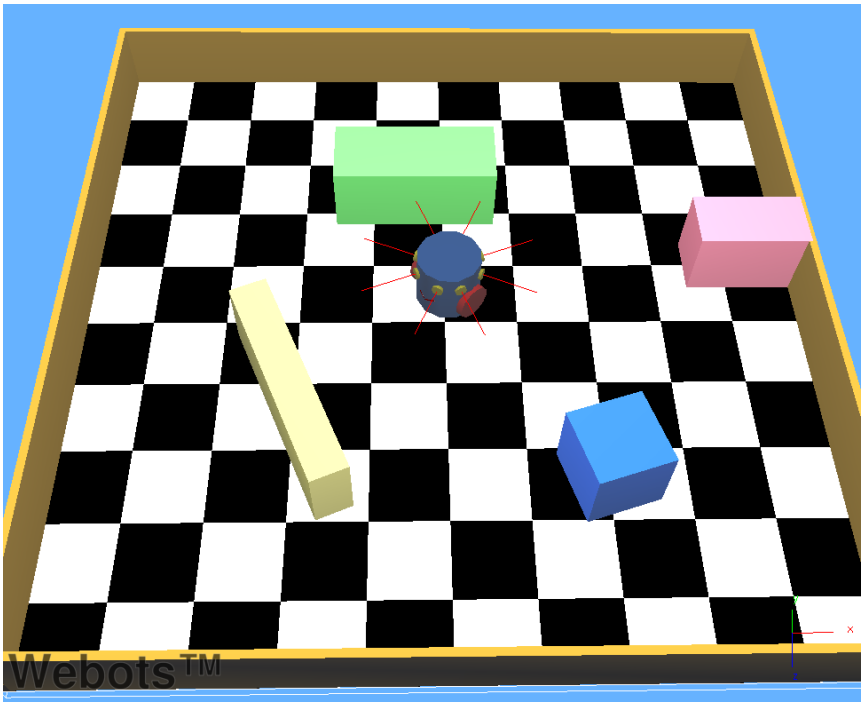


Figure 3.16: distance_sensor.wbt

3.2.5 distance_sensor.wbt

Keywords: *DistanceSensor, Braitenberg, DifferentialWheels*

In this example, a robot has eight `DistanceSensors` placed at regular intervals around its body. The robot avoids obstacles using the Braitenberg technique.

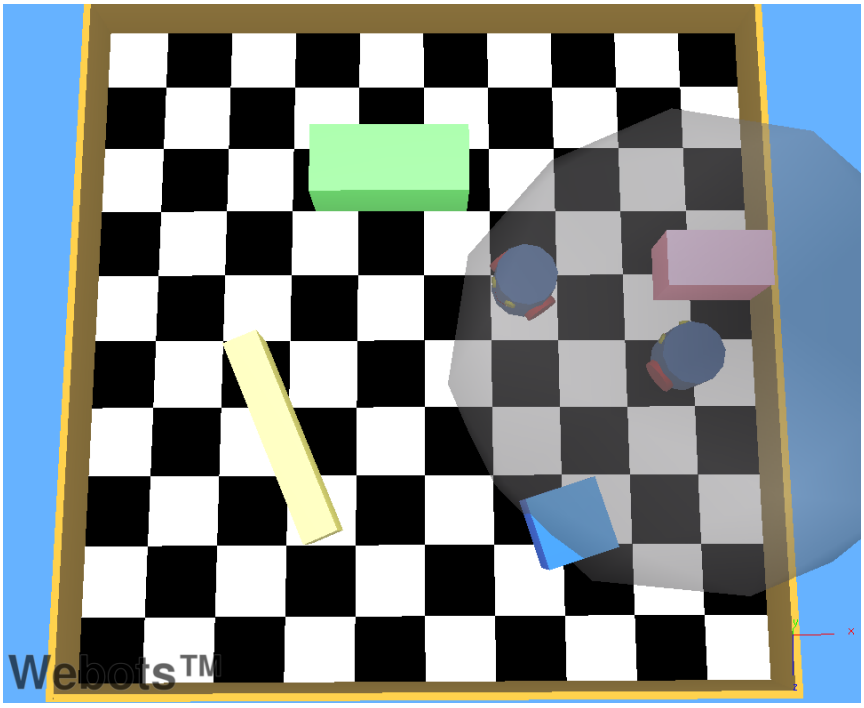


Figure 3.17: emitter_receiver.wbt

3.2.6 emitter_receiver.wbt

Keywords: *DifferentialWheels, Emitter, Receiver, infra-red transmission, USE, DEF*

In this example, there are two robots: one is equipped with an `Emitter`, the other one with a `Receiver`. Both robots move among the obstacles while the *emitter* robot sends messages to the *receiver* robot. The range of the `Emitter` device is indicated by the radius of the transparent sphere around the emitter robot. The state of the communication between the two robots is displayed in the Console. You can observe that when the *receiver* robot enters the *receiver*'s sphere, and that at the same time there is no obstacle between the robots, then the communication is established, otherwise the communication is interrupted. Note that the communication between "infra-red" `Emitters` and `Receivers` can be blocked by an obstacle, this is not the case with "radio" `Emitters` and `Receivers`.

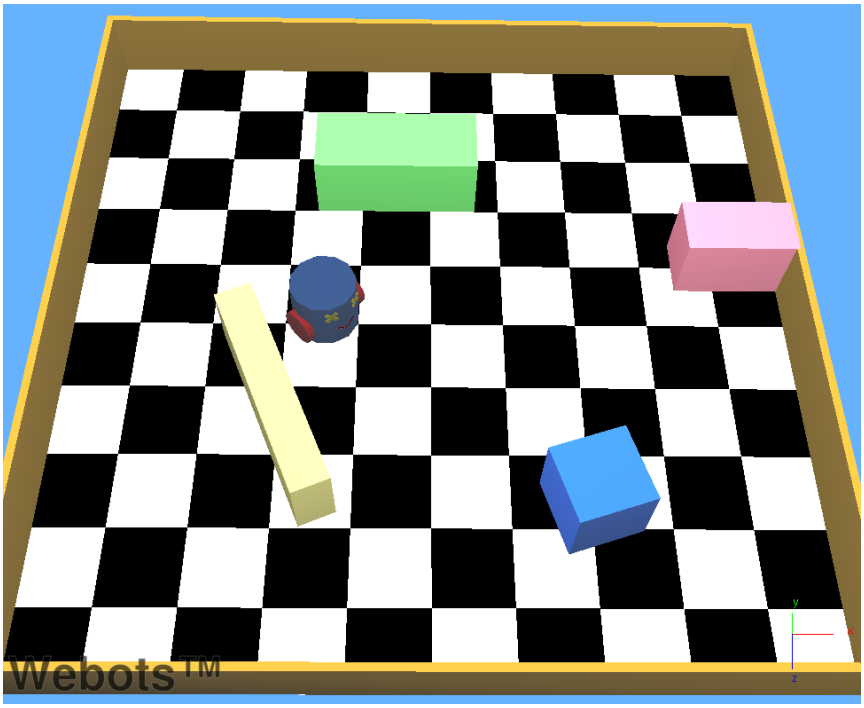


Figure 3.18: encoders.wbt

3.2.7 encoders.wbt

Keywords: *DifferentialWheels, encoders*

This example demonstrates the usage of the wheel encoders of `DifferentialWheels` robots. The controller randomly chooses target encoder positions, then it rotates its wheels until the encoder values reach the chosen target position. Then the encoders are reset and the controller chooses new random values. The robot does not pay any attention to obstacles.

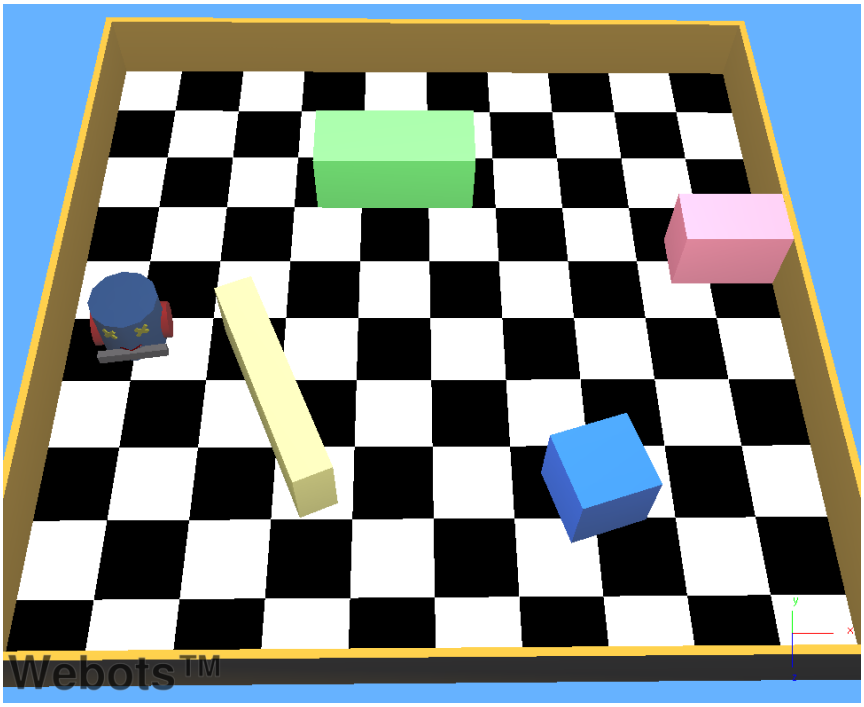


Figure 3.19: force_sensor.wbt

3.2.8 force_sensor.wbt

Keywords: *Force, TouchSensor, DifferentialWheels*

This example is nearly the same as `bumper.wbt` (see subsection 3.2.2). The only difference is that this robot uses a ”force” `TouchSensor` instead of a ”bumper”. So this robot can measure the force of each collision, which is printed in the Console window.

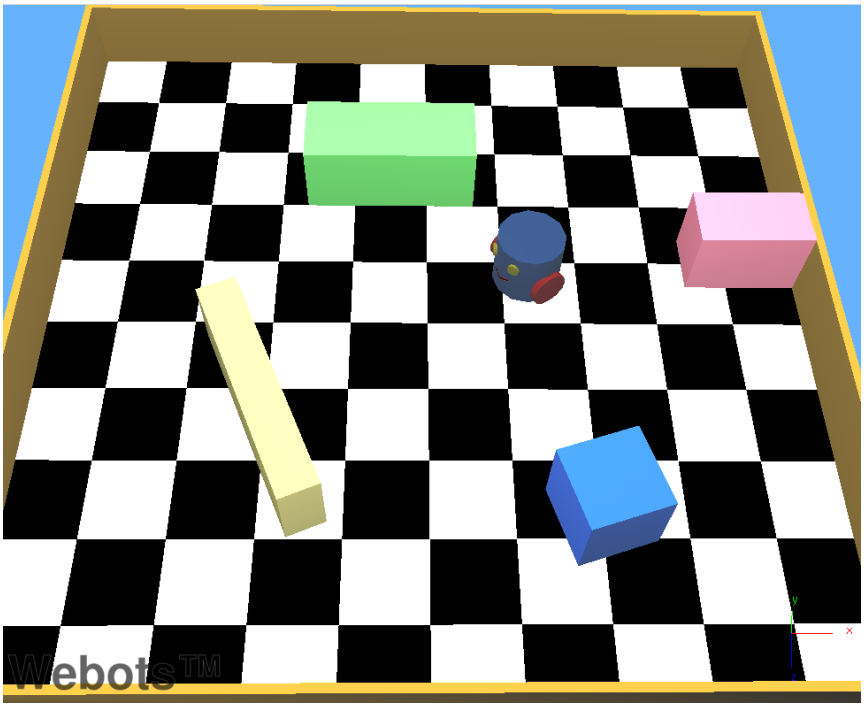


Figure 3.20: gps.wbt

3.2.9 gps.wbt

Keywords: *GPS, Supervisor, DifferentialWheels, keyboard*

This example shows two different techniques for finding out the current position of a robot. The first technique consists in using an on-board `GPS` device. The second method uses a `Supervisor` controller that reads and transmits the position info to the robot. Note that a `Supervisor` can read (or change) the position of any object in the simulation at any time. This example implements both techniques, and you can choose either one or the other with the keyboard. The 'G' key prints the robot's GPS device position. The 'S' key prints the position read by the Supervisor.

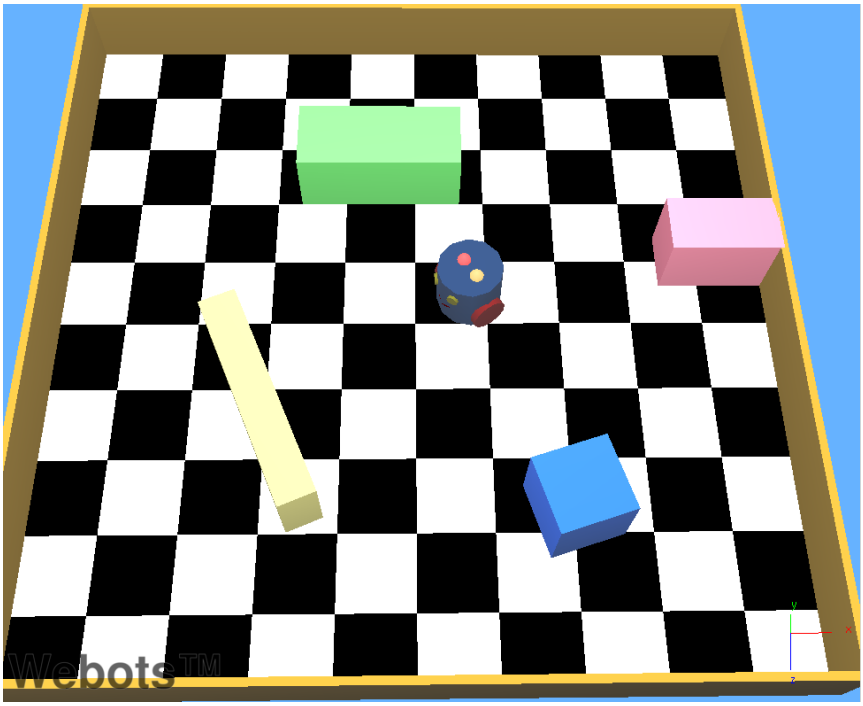


Figure 3.21: led.wbt

3.2.10 led.wbt

Keywords: *LED, DifferentialWheels*

In this example, a robot moves while randomly changing the color of three `LED`s on the top of its body. The color choice is printed in the Console.

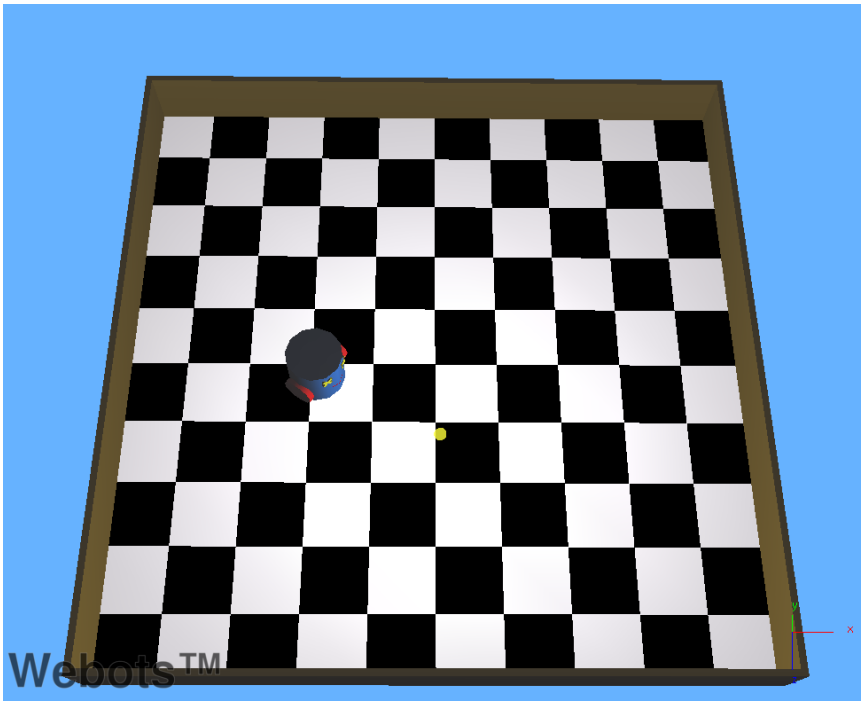


Figure 3.22: light_sensor.wbt

3.2.11 light_sensor.wbt

Keywords: *LightSensor, PointLight, lamp, light following*

In this example, the robot uses two `LightSensors` to follow a light source. The light source can be moved with the mouse; the robot will follow it.

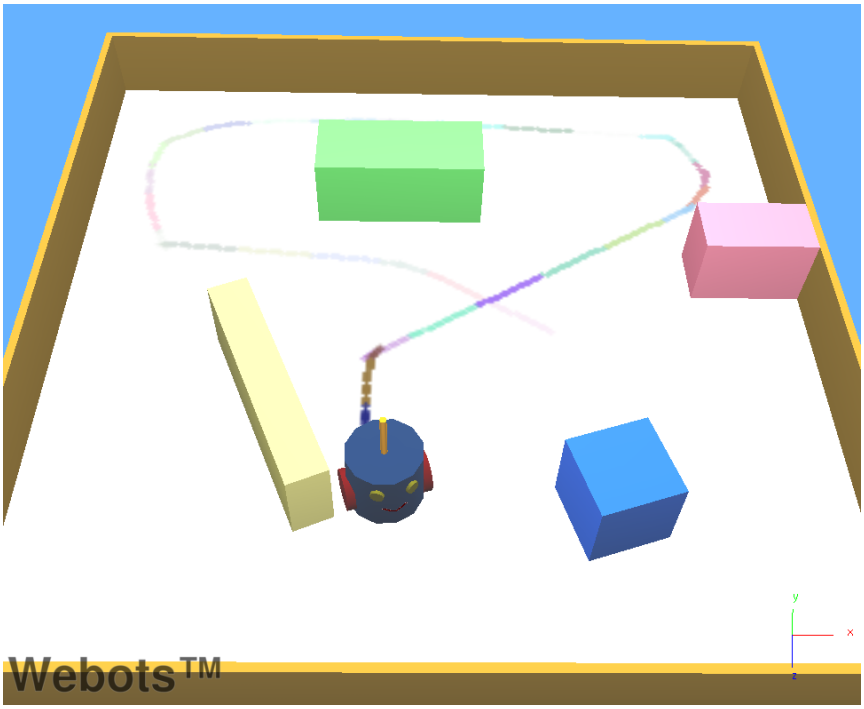


Figure 3.23: pen.wbt

3.2.12 pen.wbt

Keywords: *Pen, keyboard*

In this example, a robot uses a `Pen` device to draw on the floor. The controller randomly chooses the ink color. The ink on the floor fades slowly. Use the 'Y' and 'X' keys to switch the `Pen` on and off.

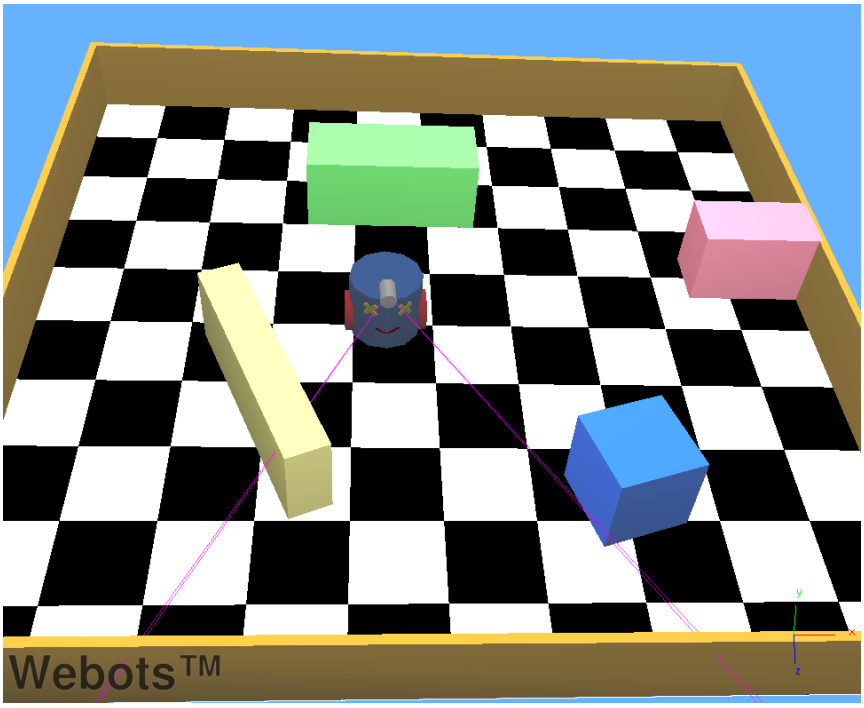


Figure 3.24: range_finder.wbt

3.2.13 range_finder.wbt

Keywords: *Range-finder, Camera, DifferentialWheels*

In this example, the robot uses a ”range-finder” `Camera` to avoid obstacles. The ”range-finder” measures the distance to objects, so the robot knows if there is enough room to move forward.

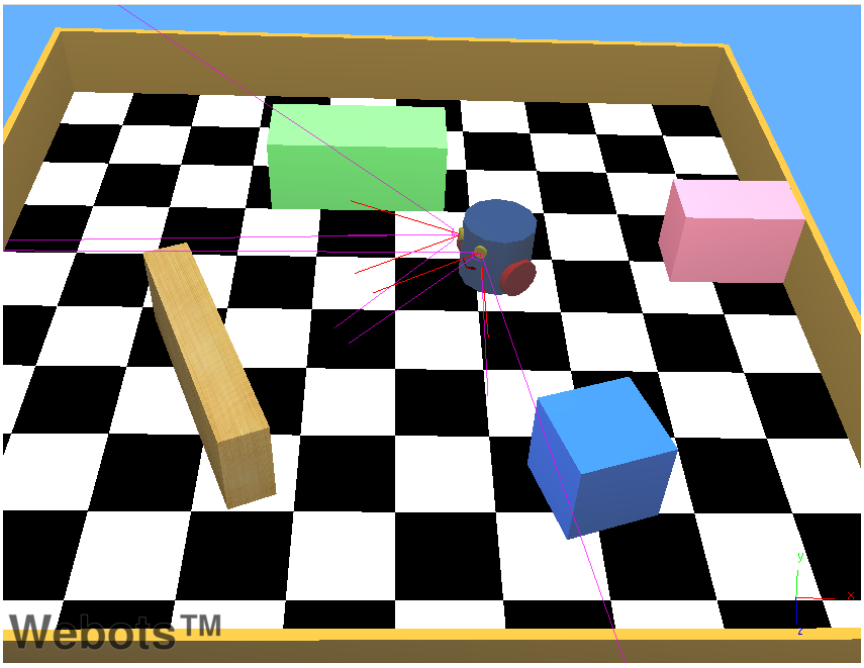


Figure 3.25: binocular.wbt

3.3 How To

This section gives various examples of complexe behaviours and/or functionalities. The world files are located in the `WEBOTS_MODULES_PATH/projects/samples/howto/world` directory, and their controllers in the `WEBOTS_MODULES_PATH/projects/samples/howto/controllers` directory. For each, the world file and its corresponding controller are named according to the behaviour they exemplify.

3.3.1 binocular.wbt

Keywords: *Stereovision, Stereoscopy, Camera*

This example simply shows how to equip a robot with two `Cameras` for stereovision. The example does not actually perform stereovision or any form of computer vision.

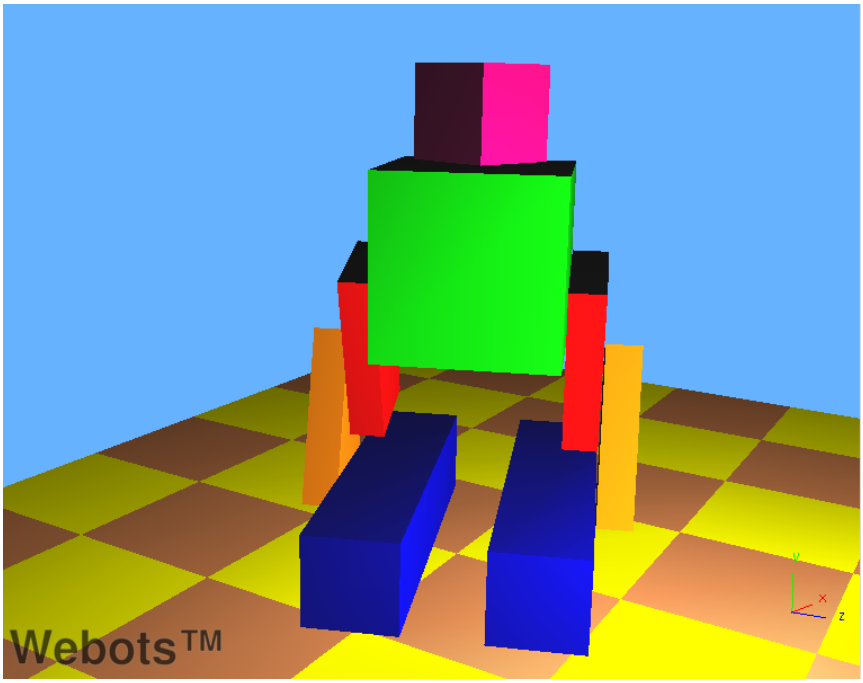


Figure 3.26: biped.wbt

3.3.2 biped.wbt

Keywords: *Humanoid robot, biped robot, power off, passive joint*

In this example, a biped robot stands up while his head rotates. After a few seconds, all the motors are turned off and the robot collapses. This example illustrates how to build a simple articulated robot and also how to turn off motor power.

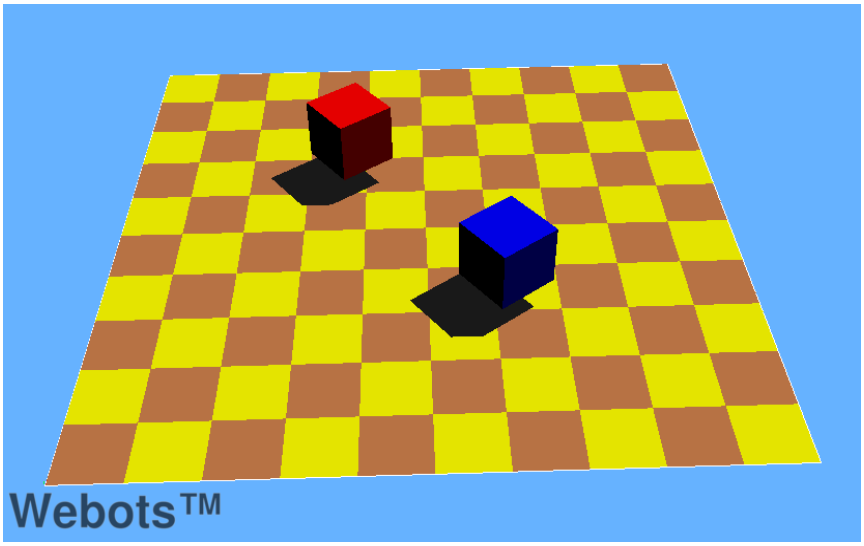


Figure 3.27: force_control.wbt

3.3.3 force_control.wbt

Keywords: *Force control, linear motor, spring and damper*

This world shows two boxes connected by a `LinearMotor`. Here, the purpose is to demonstrate the usage of the `wb_motor_set_force()` function to control a `LinearMotor` with a user specified force. In this example, `wb_motor_set_force()` is used to simulate the effect of a spring and a damper between the two boxes. When the simulation starts, the motor force is used to move the boxes apart. Then the motor force is turned off and boxes oscillate for a while now according to the spring and damping equations programmed in the controller.

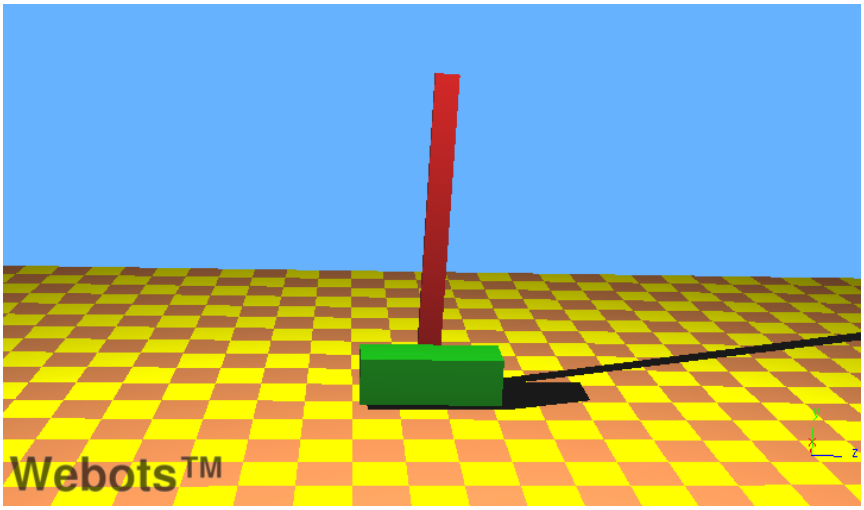


Figure 3.28: inverted_pendulum.wbt

3.3.4 inverted_pendulum.wbt

Keywords: *Inverted pendulum, PID, LinearMotor*

In this example, a robot moves from left to right in order to keep an inverted pendulum upright. This is known as the ”Inverted Pendulum Problem”, and it is solved in our example by using a PID (Proportional Integral Differential) controller.

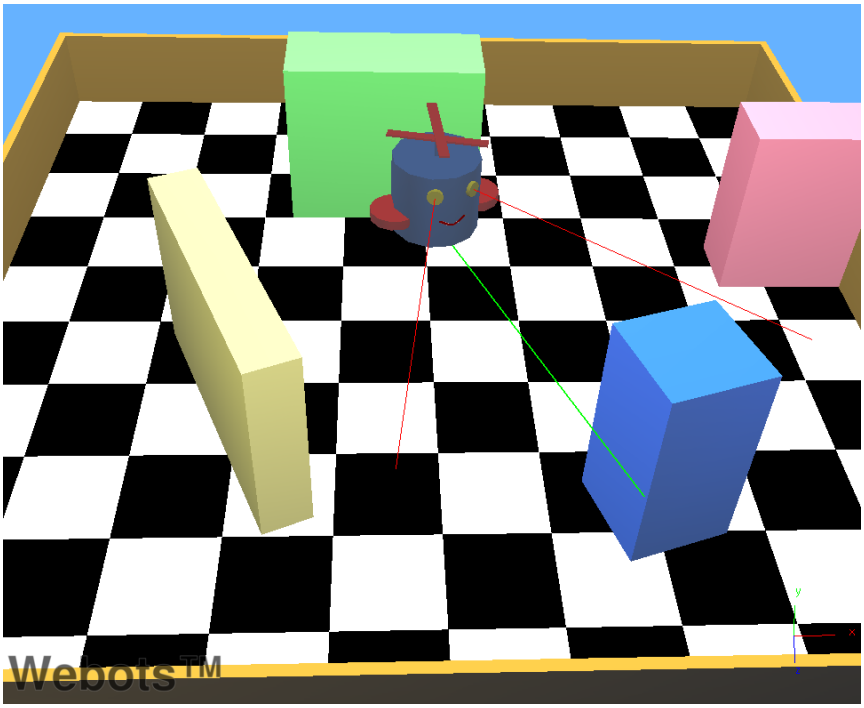


Figure 3.29: physics.wbt

3.3.5 physics.wbt

Keywords: *Physics plugin, OpenGL drawing, flying robot, Emitter, Receiver*

In this example, a robot flies using a physics plugin. This plugins is an example of:

- how to access Webots objects in the physics plugin
- how to exchange information with the controller
- how to add custom forces
- how to move objects
- how to handle collisions
- how to draw objects using OpenGL

Figure 3.30: supervisor.wbt

3.3.6 supervisor.wbt

Keywords: *Supervisor, DifferentialWheels, soccer, label, import node, restart simulation, screenshot, change controller*

This shows a simple soccer game with six robots and a referee. The `Supervisor` code demonstrates the usage of several `Supervisor` functions. For example, the `Supervisor` inserts a second ball to the simulation, changes its color, takes a picture of the 3D view, restarts the simulation, etc. In addition the `Supervisor` also plays the role of a soccer referee: it displays the current score, places the players to their initial position when a goal is scored, etc.

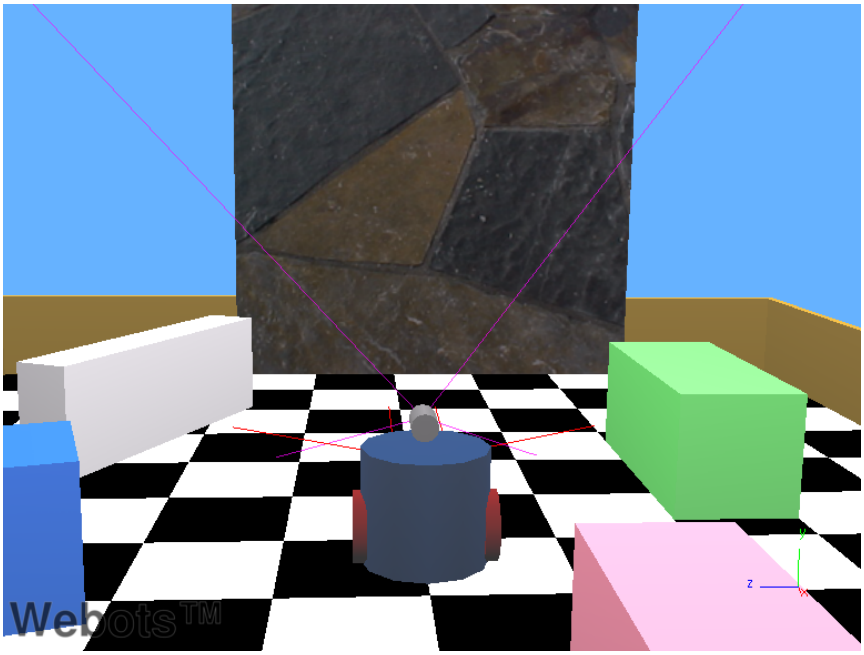


Figure 3.31: texture_change.wbt

3.3.7 texture_change.wbt

Keywords: *Supervisor, texture, wb_supervisor_field_set_*(), Camera*

In this example, a robot moves forward and backward in front of a large textured panel. The robot watches the panel with its `Camera`. Meanwhile a `Supervisor` switches the image displayed on the panel.

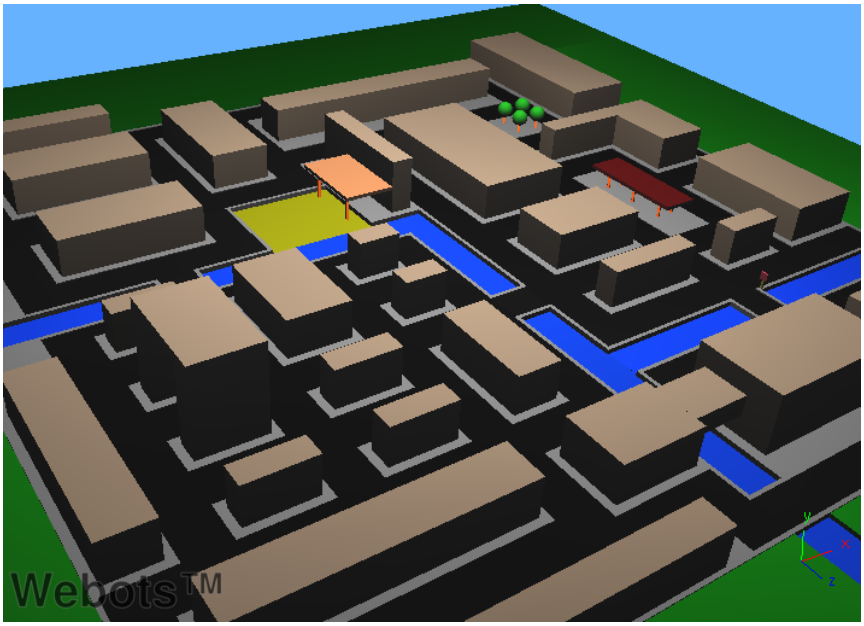


Figure 3.32: town.wbt

3.3.8 town.wbt

Keywords: *Transform, USE, DEF*

This example shows a complex city model built with various `Transform` nodes. The model makes a intensive use of the `DEF` and `USE` VRML keywords.

3.4 Geometries

This section shows the geometric primitives available in Webots. The world files for these examples are located in the `sample/geometries/worlds` directory.

In this directory, you will find the following world files :

- box.wbt
- cone.wbt
- convex_polygon.wbt
- cylinder.wbt
- high_resolution_indexedfaceset.wbt
- non_convex_polygon.wbt
- physics_primitives.wbt
- polyhedra.wbt
- sphere.wbt
- textured_shapes.wbt
- webots_box.wbt

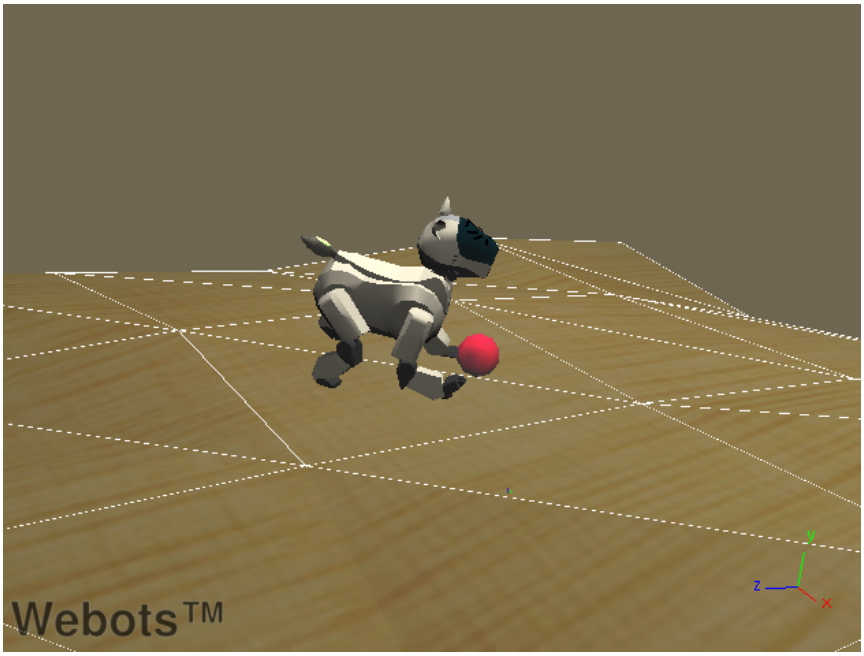


Figure 3.33: aibo_ers210_rough.wbt

3.5 Real Robots

This section discusses worlds containing models of real robots. The world files for these examples are located in the `robots/(robot_name)/worlds` directory, and the corresponding controllers are located in the `robots/(robot_name)/controllers` directory.

3.5.1 aibo_ers210_rough.wbt

Keywords: *Aibo, Legged robot, uneven ground, IndexedFaceSet, texture*

In this example, you can see a silver Aibo ERS-210 robot walking on an uneven floor while a ball rolls and falls off. The uneven floor is principally made of a `IndexedFaceSet`.

Figure 3.34: aibo_ers7.wbt

3.5.2 aibo_ers7.wbt

Keywords: *Aibo, ERS-7, legged robot, soccer field, Charger, toys, beacon, bone*

In this example, you can see a silver Aibo ERS-7 robot walking on a textured soccer field. On this field you can also see its toys : a ball, a charger and a bone.

Figure 3.35: alice.wbt

3.5.3 alice.wbt

Keywords: *Alice, Braitenberg, DistanceSensor*

In this example, you can see an Alice robot moving inside an arena while avoiding the walls. Its world file is in the `others/worlds` directory. Like many others, this example uses the `braitenberg` controller.

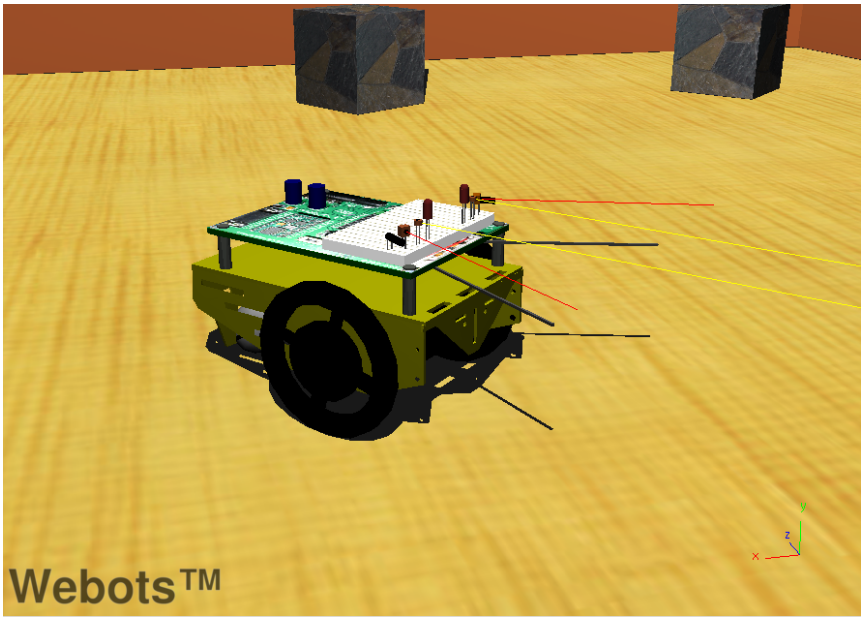


Figure 3.36: boebot.wbt

3.5.4 boebot.wbt

Keywords: *BoeBot, DistanceSensor, LED*

In this example, BoeBot moves inside an arena while avoiding the walls. When the robot detects an obstacle with one of its `DistanceSensors`, it turns the corresponding `LED` on.

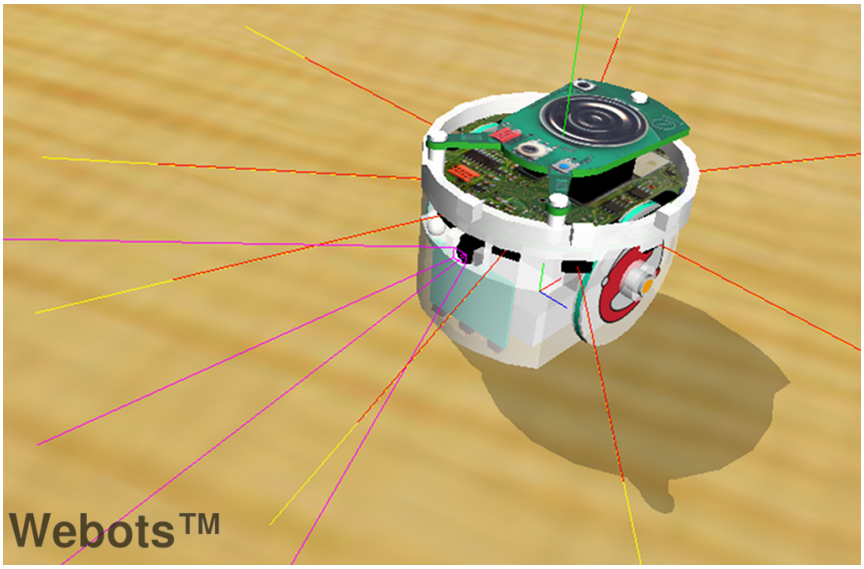


Figure 3.37: e-puck.wbt

3.5.5 e-puck.wbt

Keywords: *DifferentialWheels, texture, Braitenberg, Accelerometer, Odometry, E-puck*

In this example, you can see the e-puck robot avoiding obstacles inside an arena by using the Braitenberg technique. The odometry of the e-puck is computed at each simulation steps. The accelerometer values and an estimation the coverage distance and the orientation of the e-puck are displayed. The source code for this controller is in the `WEBOTS_MODULES_PATH/projects/default/controllers/braitenberg` directory.

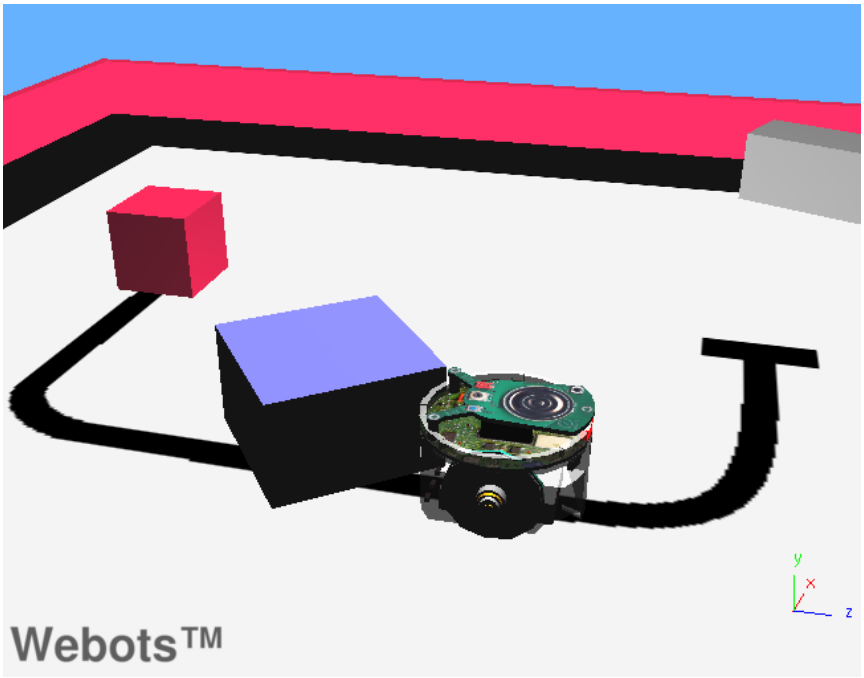


Figure 3.38: e-puck_line.wbt

3.5.6 e-puck_line.wbt

Keywords: *DifferentialWheels, line following, texture, behavior-based robotics, E-puck*

In this example, you can see the E-puck robot following a black line drawn on the ground. In the middle of this line there is an obstacle which the robot is unable to avoid. This example has been developed as a practical assignment on behavior-based robotics. When completed, the controller should allow the E-puck robot to avoid this obstacle and recover its path afterwards. A solution for this assignment is shown in the world e-puck_line_demo.wbt (see subsection 3.5.7). The source code for this controller is in the `e-puck_line` directory.

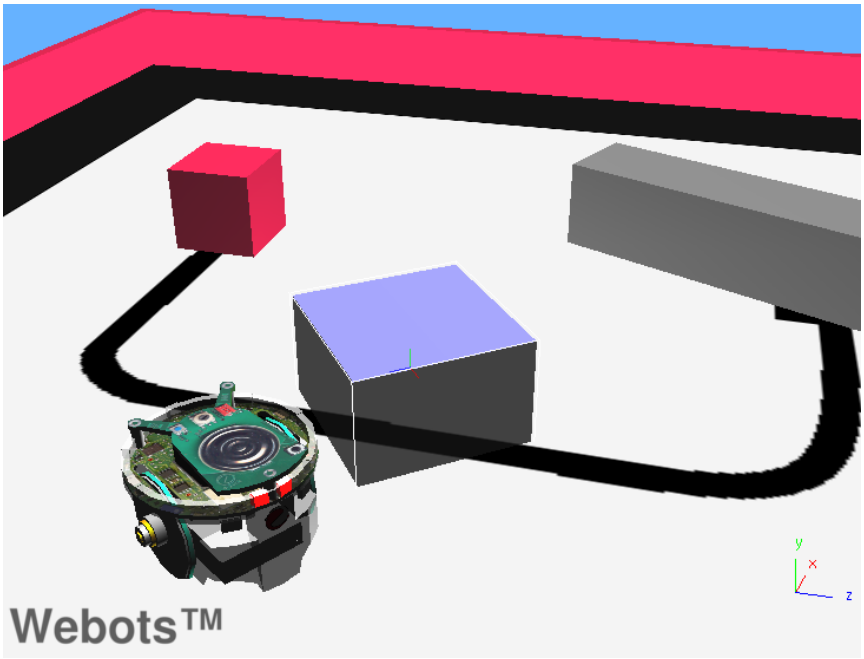


Figure 3.39: e-puck_line_demo.wbt

3.5.7 e-puck_line_demo.wbt

Keywords: *DifferentialWheels, line following, texture, behavior-based robotics, E-puck*

This example is the solution for the assignment given in the `e-puck_line_demo.wbt` example (see subsection 3.5.6). In this case, you can see that the robot avoids the obstacle, then recovers its path along the line. As the controller used in this world is the solution to the assignment, the source code is not distributed.

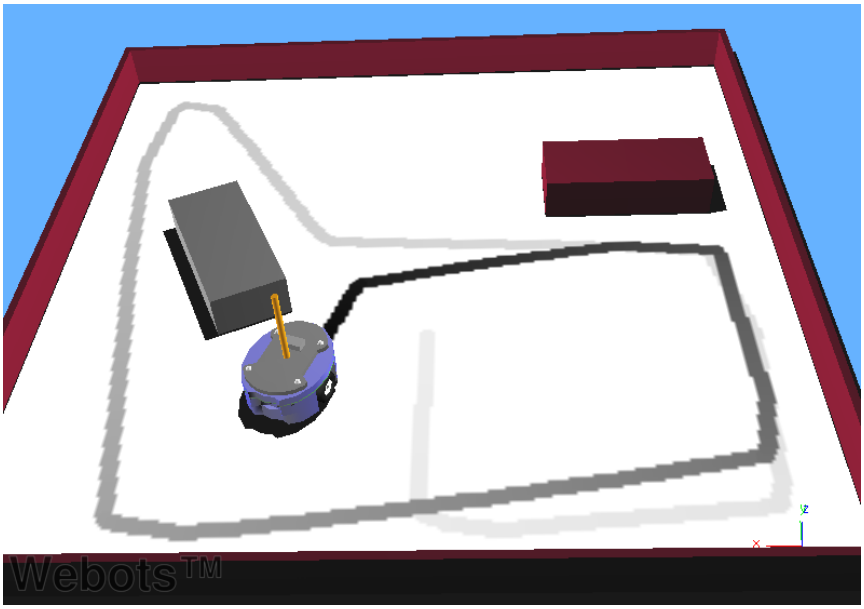


Figure 3.40: hemisson_cross_compilation.wbt

3.5.8 hemisson_cross_compilation.wbt

Keywords: *DifferentialWheels, Pen, cross-compilation, texture, Hemisson*

In this example, a Hemisson robot moves on a white floor while avoiding the obstacles. Its `Pen` device draws a black line which slowly fades. This example is a cross-compilation example for the real Hemisson robot. The source code for this controller is in the `hemisson` directory.

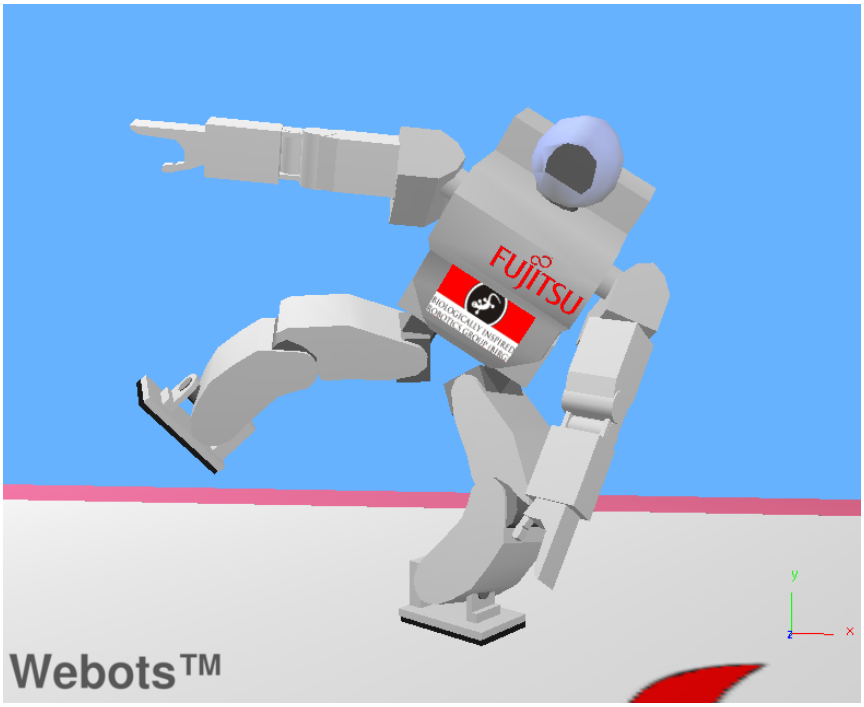


Figure 3.41: hoap2_sumo.wbt

3.5.9 hoap2_sumo.wbt

Keywords: *Robot node, humanoid, texture, dancing, Hoap 2, IndexedFaceSet, RotationalMotor, active joint, force, TouchSensor*

In this example, a Hoap2 robot from Fujitsu performs the Shiko dance (the dance which sumos perform before a match). This robot is equipped with `TouchSensors` on the soles of its feet; it measures and logs the pressure exerted by its body on the ground. The source code for this controller is in the `hoap2` directory.

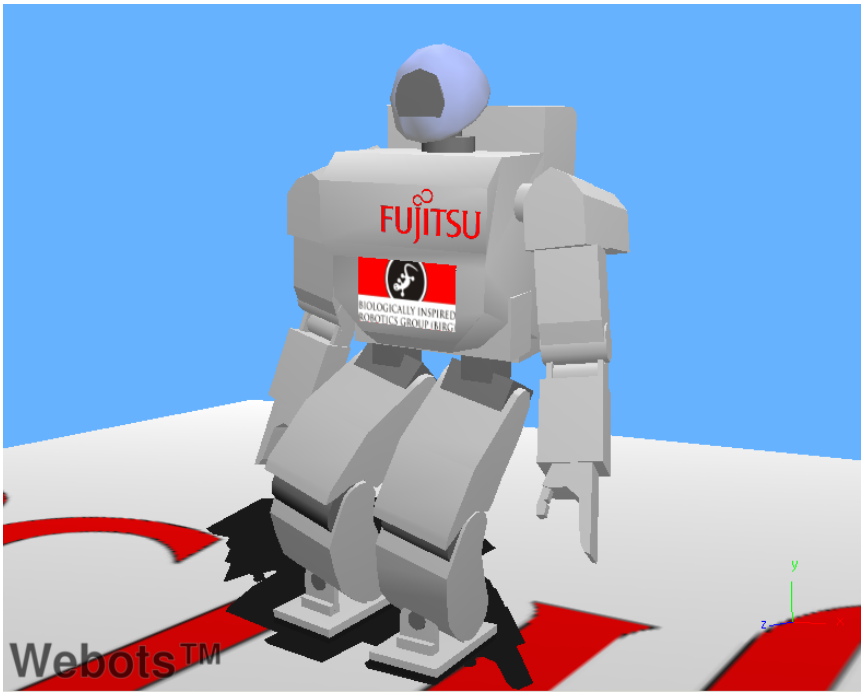


Figure 3.42: hoap2_walk.wbt

3.5.10 hoap2_walk.wbt

Keywords: *Robot node, humanoid, texture, walking, Hoap 2, IndexedFaceSet, RotationalMotor, active joint, force, TouchSensor*

In this example, a Hoap2 robot from Fujitsu walks straight forward on a tatami. This robot is equipped with `TouchSensors` on the soles of its feet; it measures and logs the pressure exerted by its body on the ground. The source code for this controller is in the `hoap2` directory.

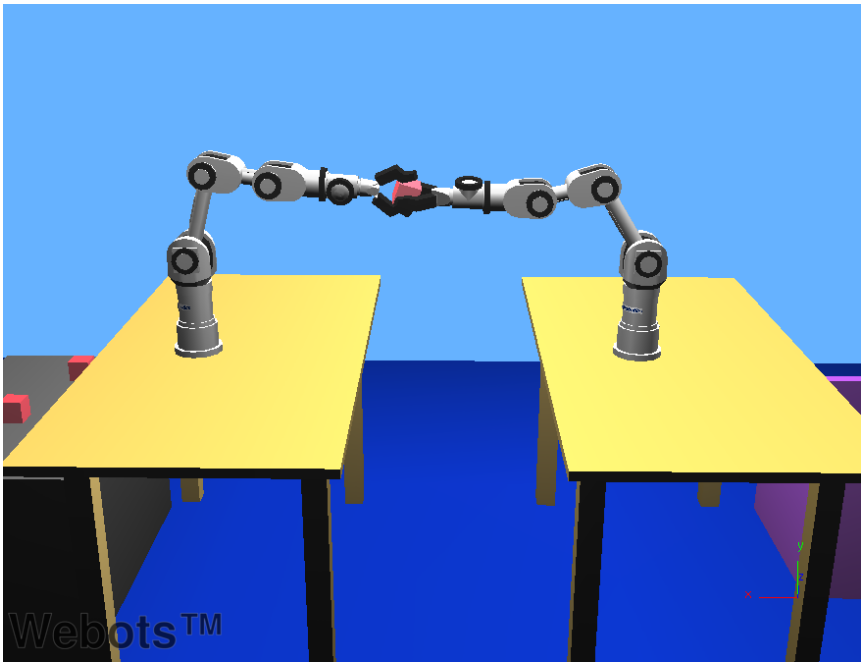


Figure 3.43: ipr_collaboration.wbt

3.5.11 ipr_collaboration.wbt

Keywords: *Robot node, robotic arm, collaboration, TCP/IP, client program, IPR, IndexedFaceSet, RotationalMotor, active joint*

In this example, two IPR robots from Neuronics work together to put three red cubes into a basket which is on the opposite side of the world. All the IPR robots use the same controller, whose source code is in the `ipr_serial` directory. This particular example uses, in addition to this controller, a client program which coordinates the movements of the robots. The source code for this client is in the `ipr_serial/client/ipr_collaboration.c` file.

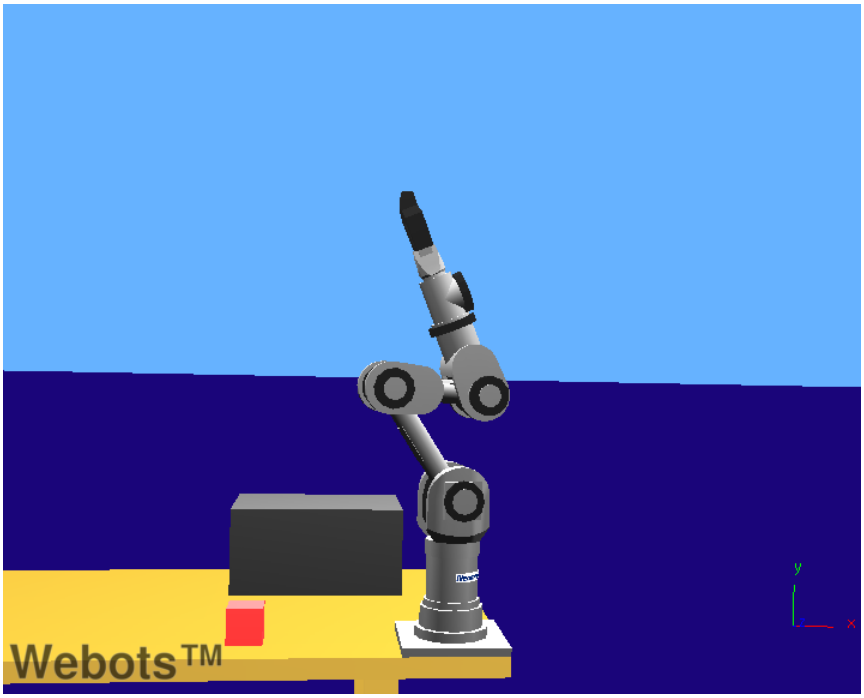


Figure 3.44: ipr_cube.wbt

3.5.12 ipr_cube.wbt

Keywords: *Robot node, robotic arm, TCP/IP, client program, IPR, IndexedFaceSet, RotationalMotor, active joint*

In this example, an IPR robots from Neuronics moves a small red cube onto a bigger one. All the IPR robots use the same controller, whose source code is in the `ipr_serial` directory. This example also uses a client program which drives the movements of the robot. The source code of this client is in the `ipr_serial/client/ipr_cube.c` file.

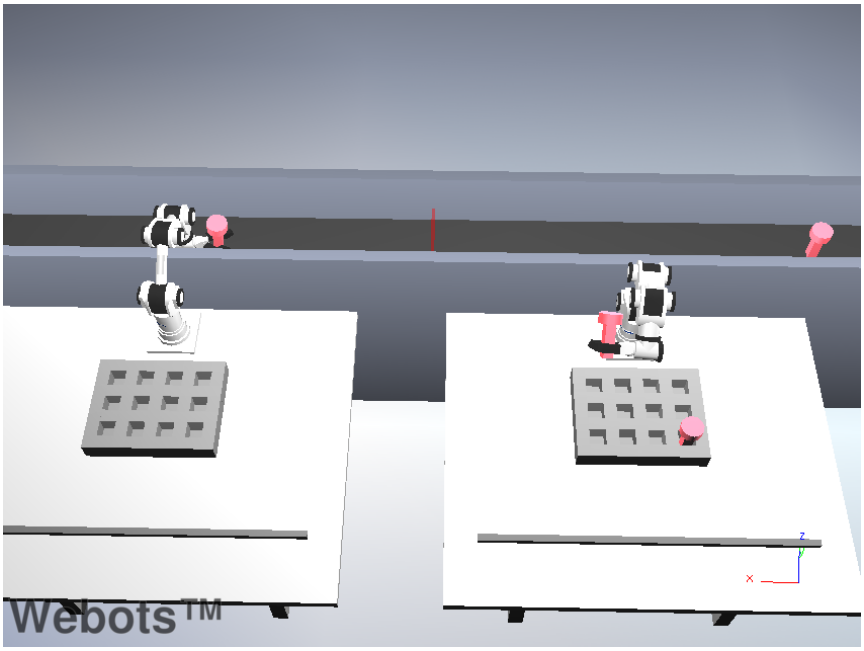


Figure 3.45: ipr_factory.wbt

3.5.13 ipr_factory.wbt

Keywords: *Robot node, Supervisor, conveyor belt, robotic arm, TCP/IP, client program, IPR, IndexedFaceSet, RotationalMotor, active joint*

In this example, two IPR robots from Neuronics take industrial parts from a conveyor belt and place them into slots. One of the robots detects the objects using an infrared sensor on the conveyor belt, while the other one waits. All the IPR robots use the same controller, whose source code is in the `ipr_serial` directory. This example also uses a client program which coordinates the movements of the robots. The source code for this client is in the file `ipr_serial/client/ipr_factory.c`.

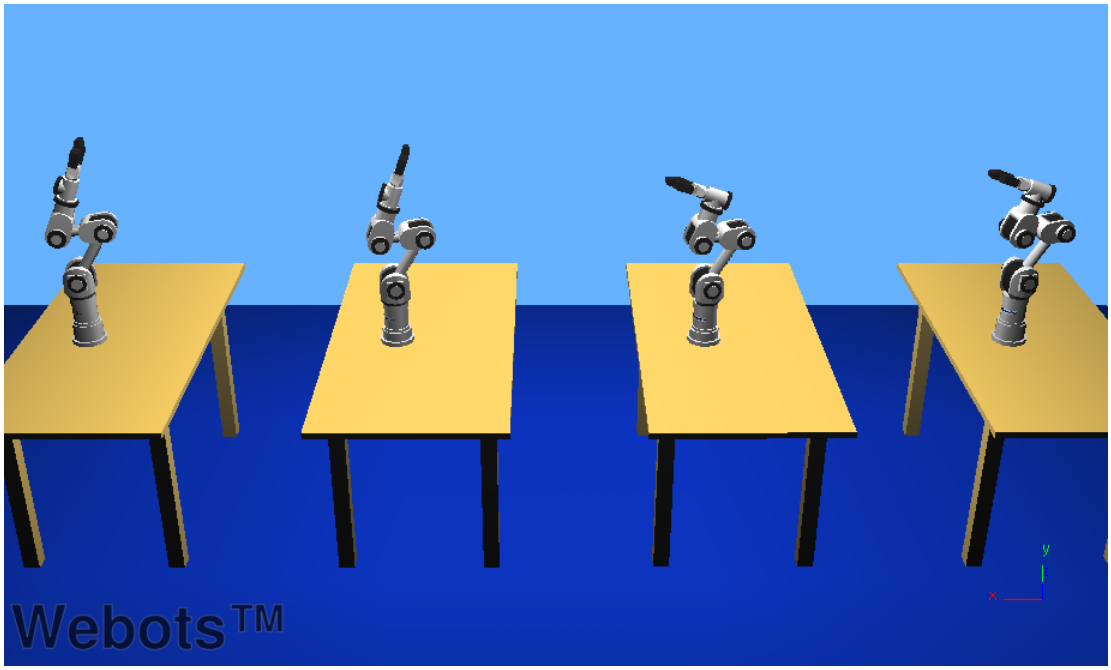


Figure 3.46: ipr_models.wbt

3.5.14 ipr_models.wbt

Keywords: *Robot node, robotic arm, TCP/IP, IPR, IndexedFaceSet, RotationalMotor, active joint*

In this example, you can see all the different types of IPR model provided by Webots : HD6M180, HD6Ms180, HD6M90 and HD6Ms90. This world is intended to be the example from which you can copy the models of IPR robots into your own worlds. All the IPR robots use the same controller, whose source code is in the `ipr_serial` directory.

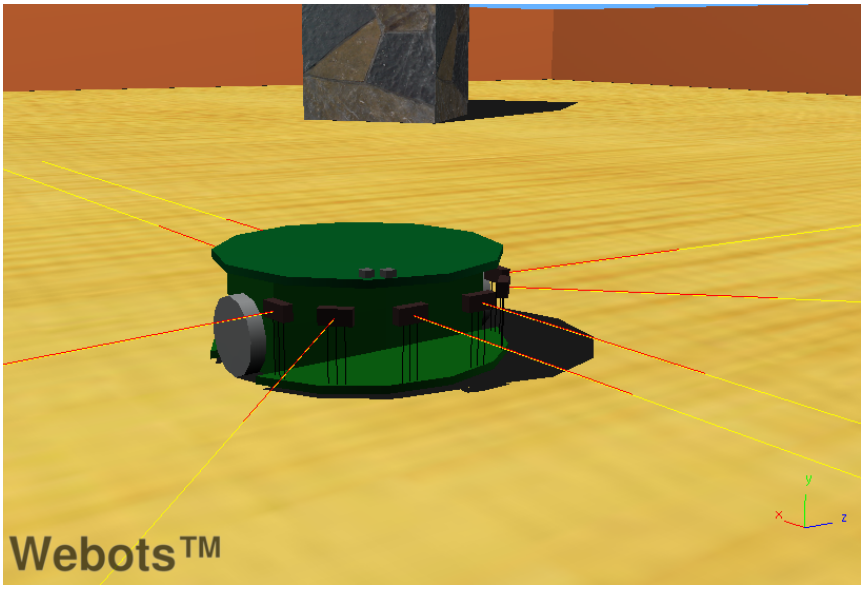


Figure 3.47: khepera.wbt

3.5.15 khepera.wbt

Keywords: *DifferentialWheels, DistanceSensor, Braitenberg, texture, Khepera*

In this example, you can see a Khepera robot from K-Team moving inside an arena while avoiding the walls. Like many other examples, this one uses the `braitenberg` controller. The source code for this controller is located in the `WEBOTS_MODULES_PATH/projects/default/controllers/braitenberg` directory.

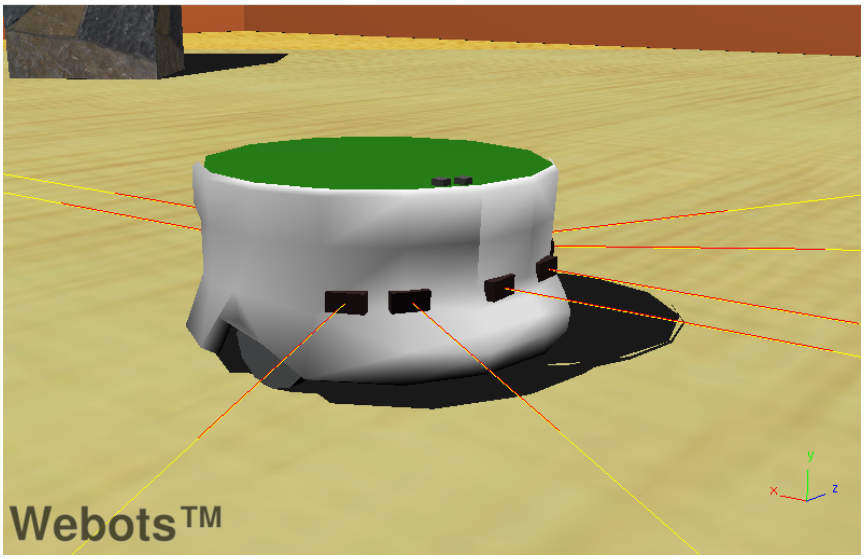


Figure 3.48: khepera2.wbt

3.5.16 khepera2.wbt

Keywords: *DifferentialWheels, DistanceSensor, Braitenberg, texture, Khepera II*

In this example, you can see a Khepera II robot from K-Team moving inside an arena while avoiding the walls. Like many other examples, this one uses the `braitenberg` controller. The source code for this controller is in the `WEBOTS_MODULES_PATH/projects/default/controllers/braitenberg` directory.

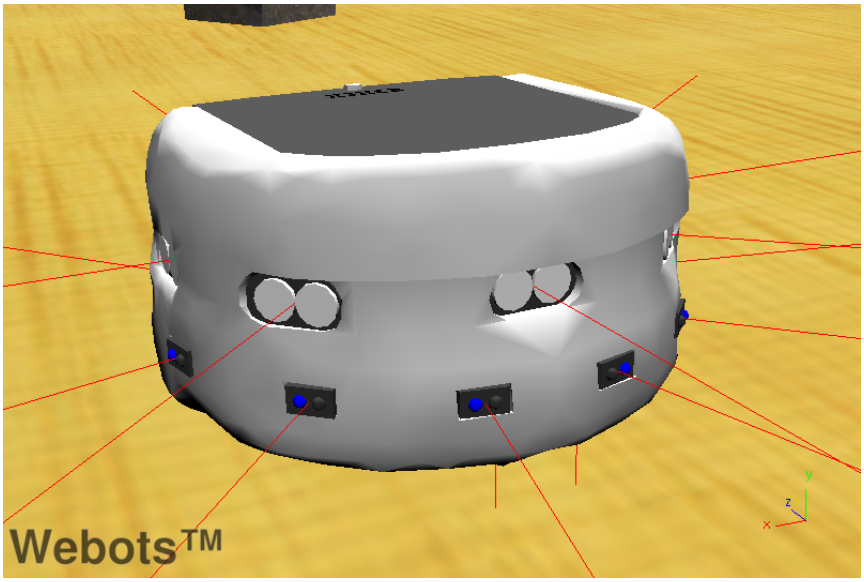


Figure 3.49: khepera3.wbt

3.5.17 khepera3.wbt

Keywords: *DifferentialWheels, DistanceSensor, Braitenberg, texture, Khepera III*

In this example, you can see a Khepera III robot from K-Team moving inside an arena while avoiding the walls. Like many other examples, this one uses the `braitenberg` controller. The source code for this controller is in the `WEBOTS_MODULES_PATH/projects/default/controllers/braitenberg` directory.

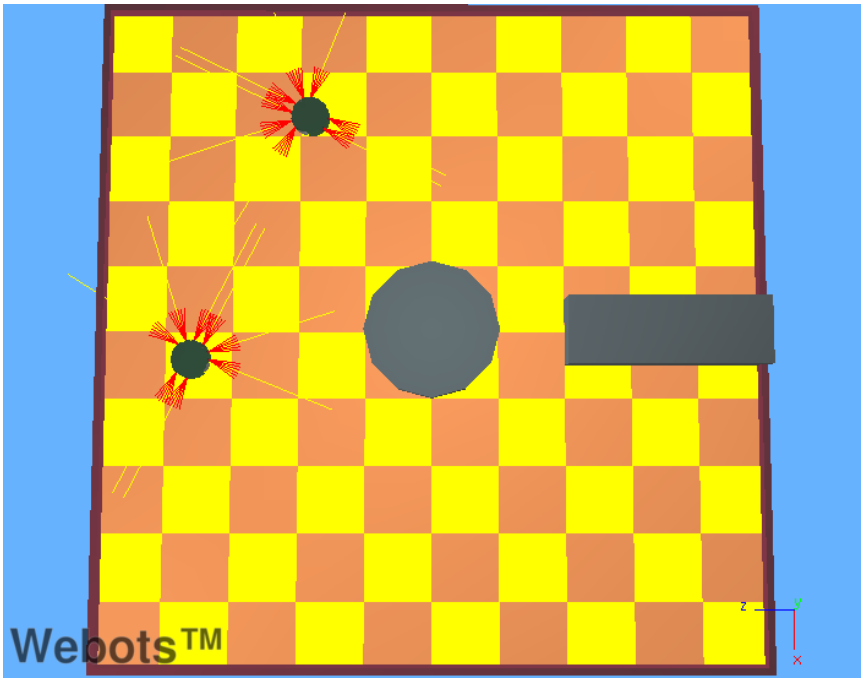


Figure 3.50: khepera_kinematic.wbt

3.5.18 khepera_kinematic.wbt

Keywords: *DifferentialWheels, DistanceSensor, Braitenberg, Kinematic, Khepera*

In this example, you can see two Khepera robots from K-Team moving inside an arena while avoiding each other and the walls. It is a good example of how to use teh kinematic mode of Webots. Like many other examples, this one uses the `braitenberg` controller. The source code for this controller is in the `WEBOTS_MODULES_PATH/projects/default/controllers/braitenberg` directory.

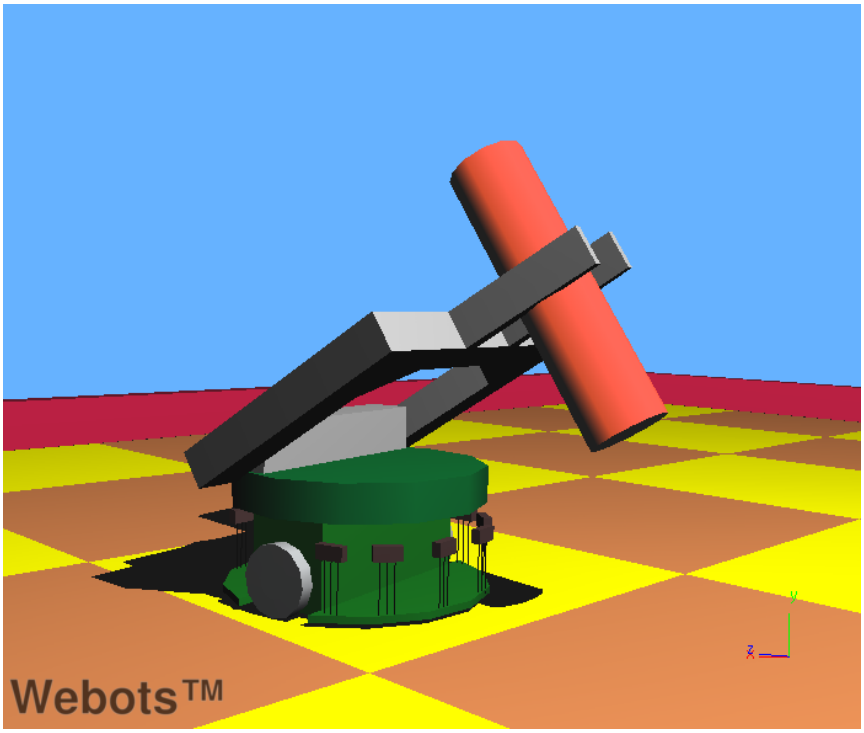


Figure 3.51: khepera_gripper.wbt

3.5.19 khepera_gripper.wbt

Keywords: *DifferentialWheels, Gripper, Khepera*

In this example, you can see a Khepera robot from K-Team equipped with a gripper. The robot uses its gripper to grab a stick, move a bit with it and drop it on the ground. This behavior is repeated endlessly. The source code for this controller is in the `khepera_gripper` directory.

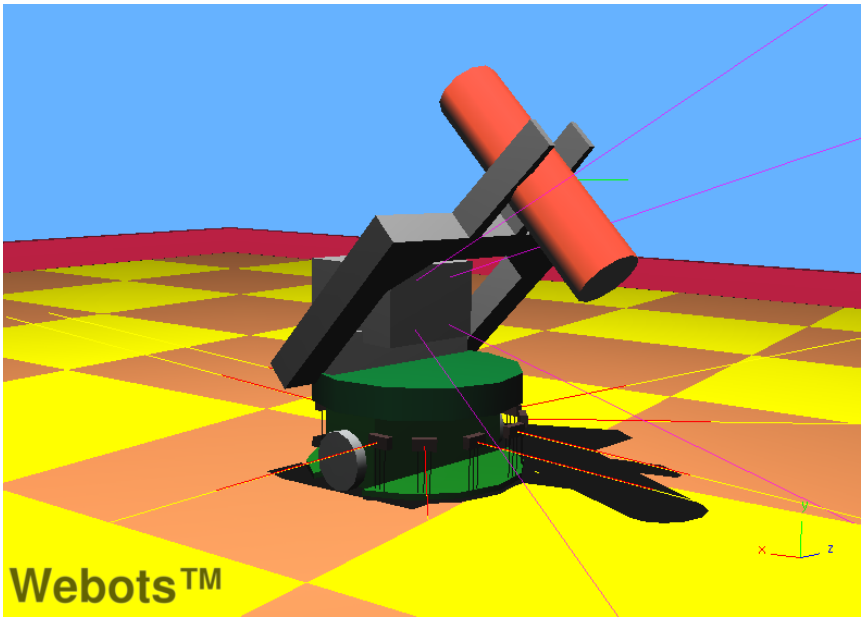


Figure 3.52: khepera_gripper_camera.wbt

3.5.20 khepera_gripper_camera.wbt

Keywords: *DifferentialWheels, Gripper, Camera, Khepera*

In this example, you can see a Khepera robot from K-Team equipped with a gripper and a `Camera` device. The robot uses its gripper to grab a stick, move a bit with it and drop it on the floor. This behavior is repeated endlessly. In this world, the robot does not analyse the images it takes with its camera. The source code for this controller is in the `khepera_gripper` directory.

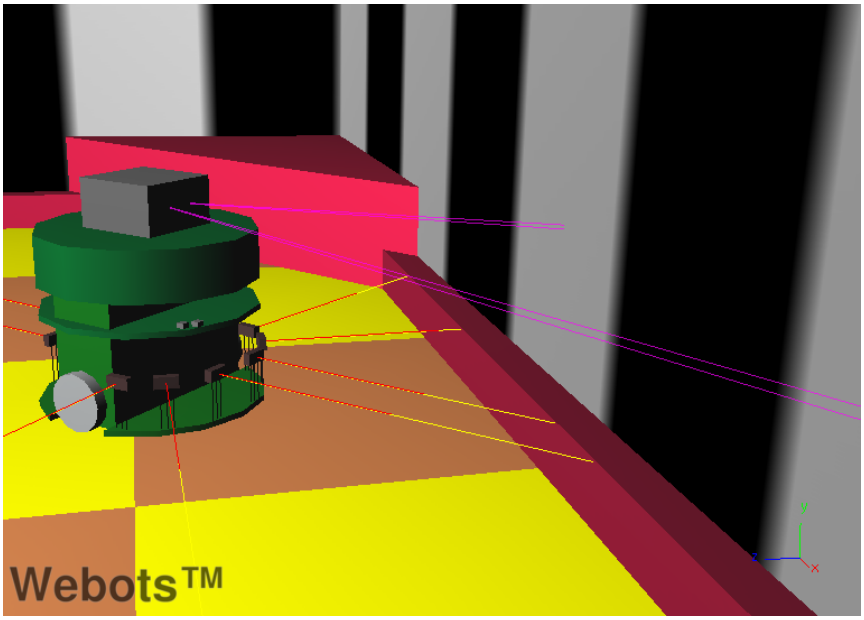


Figure 3.53: khepera_k213.wbt

3.5.21 khepera_k213.wbt

Keywords: *DifferentialWheels, DistanceSensor, K213, linear Camera, Khepera*

In this example, you can see a Khepera robot from K-Team equipped with a K213 `Camera` device. This camera is a linear vision turret with greyscale images. Using this device, the robot is able to translate the information contained in the image into text and print this result in the Console window. When you load this world, the robot will not begin to move immediately. It will give you enough time to read the explanations printed in the Console window concerning this world. The source code for this controller is in the `khepera_k213` directory.

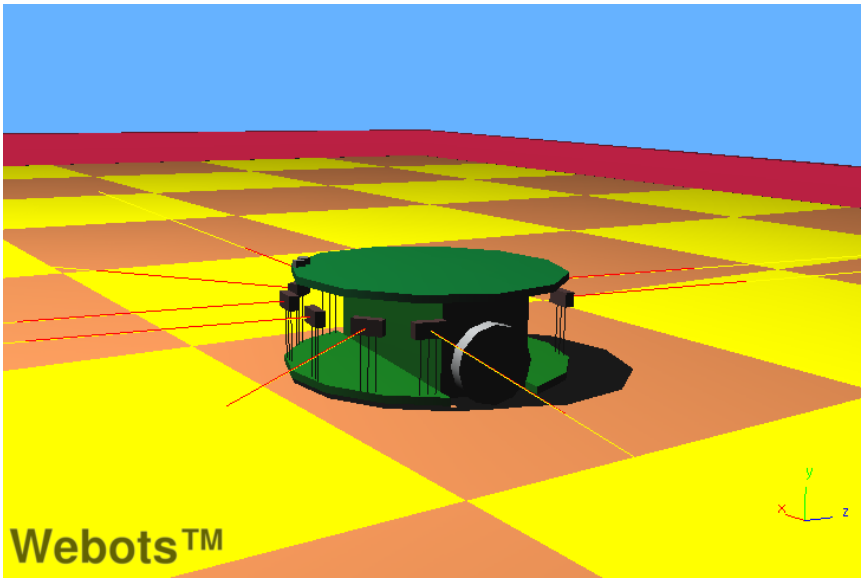


Figure 3.54: khepera_pipe.wbt

3.5.22 khepera_pipe.wbt

Keywords: *DifferentialWheels, UNIX pipe, client program, Khepera*

In this example, you can see a Khepera robot from K-Team inside an arena. The controller for this robot opens a UNIX pipe in order to receive commands using the Khepera serial communication protocol. This example is provided with a sample client program which interacts with the controller of the robot to make it move straight forward until it detects an obstacle. This client program `client` must be launched separately from Webots. The source code for this controller and for the client program are in the `pipe` directory.

As this example is based on standard UNIX pipes, it does not work under Windows.

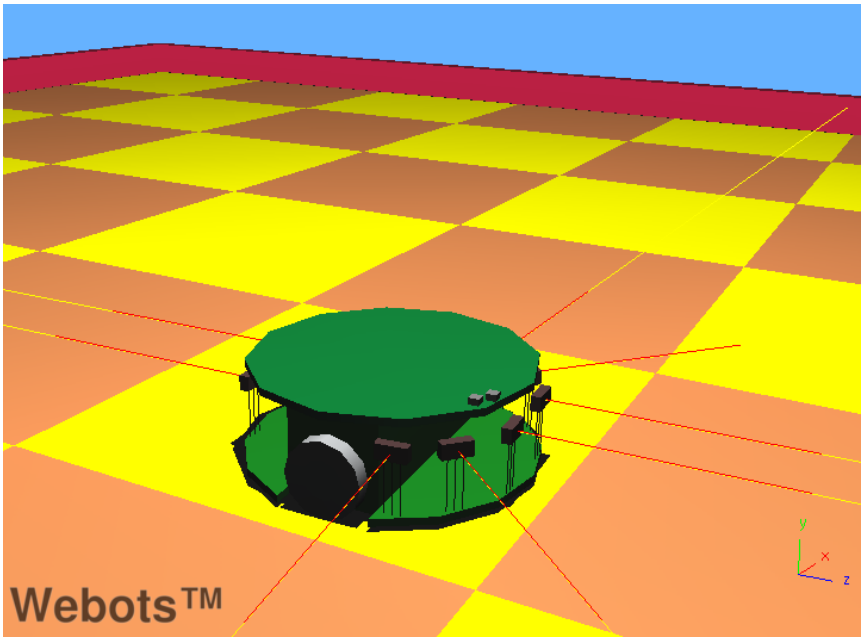


Figure 3.55: khepera_tcpip.wbt

3.5.23 khepera_tcpip.wbt

Keywords: *DifferentialWheels, TCP/IP, client program, Khepera*

In this example, you can see a Khepera robot from K-Team inside an arena. The controller for this robot acts as a TCP/IP server, waiting for a connection. Through this connection, the robot can receive commands using the Khepera serial communication protocol. This example is provided with a sample client program which displays a command prompt, with which you can control the movements of the robot. This client program `client` must be launched separately from Webots. The source code for this controller and for the client program are in the `tcpip` directory.

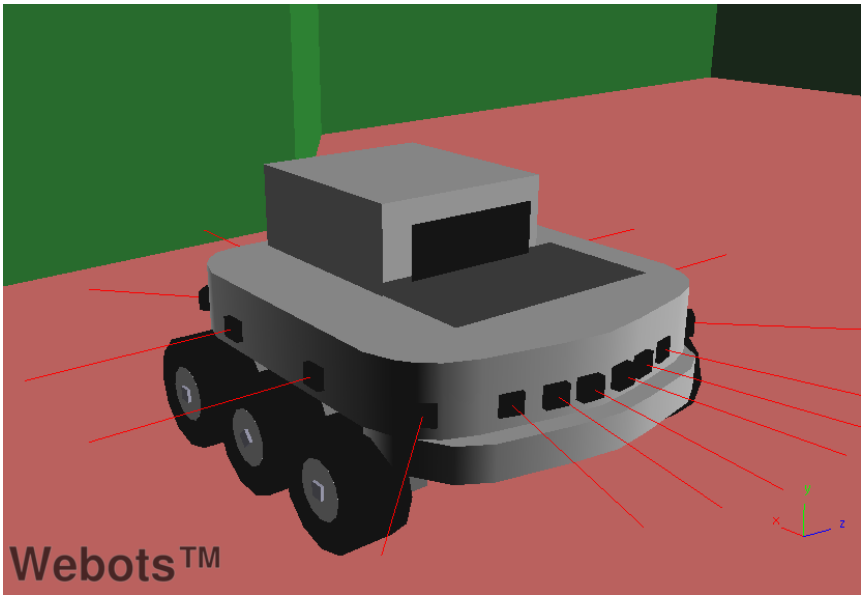


Figure 3.56: koala.wbt

3.5.24 koala.wbt

Keywords: *DifferentialWheels, DistanceSensor, Braitenberg, Koala*

In this example, you can see a Koala robot from K-Team moving inside an arena while avoiding the walls. Like many other examples, this one uses the `braitenberg` controller. The source code for this controller is located in the `WEBOTS_MODULES_PATH/projects/default/controllers/braitenberg` directory.

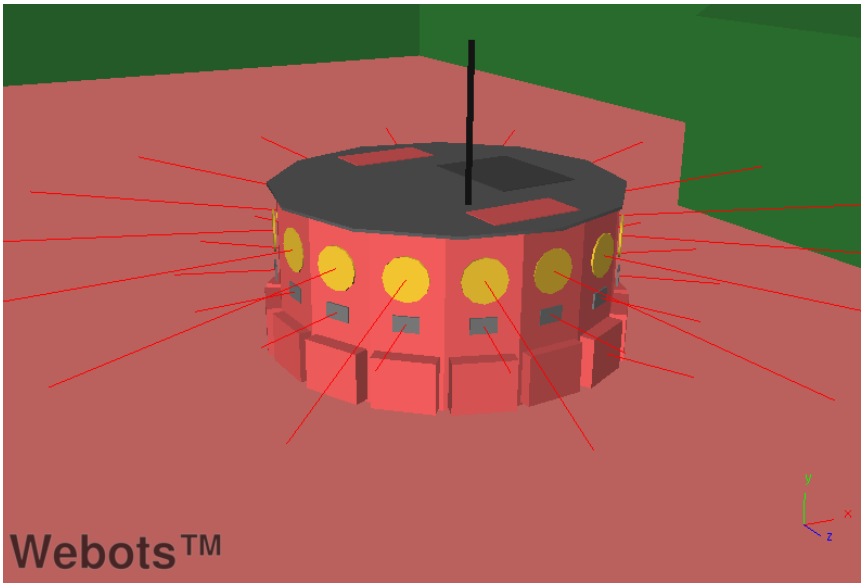


Figure 3.57: magellan.wbt

3.5.25 magellan.wbt

Keywords: *DifferentialWheels, DistanceSensor, Braitenberg, Magellan*

In this example, you can see a Magellan robot moving inside an arena while avoiding the walls. As this robot is no longer produced, its world file is in the `others/worlds` directory. Like many other examples, this one uses the `braitenberg` controller. The source code for this controller is located in the `WEBOTS_MODULES_PATH/projects/default/controllers/braitenberg` directory.

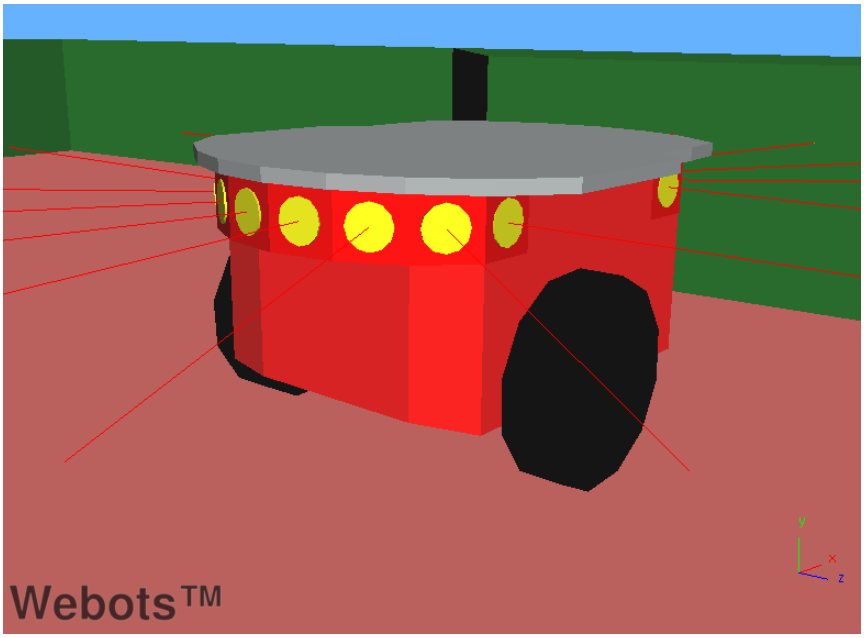


Figure 3.58: pioneer2.wbt

3.5.26 pioneer2.wbt

Keywords: *DifferentialWheels, DistanceSensor, Braitenberg, Pioneer 2*

In this example, you can see a Pioneer 2 robot from ActivMedia Robotics moving inside an arena while avoiding the walls. Like many other examples, this one uses the `braitenberg` controller. The source code for this controller is in the `WEBOTS_MODULES_PATH/projects/default/controllers/braitenberg` directory.

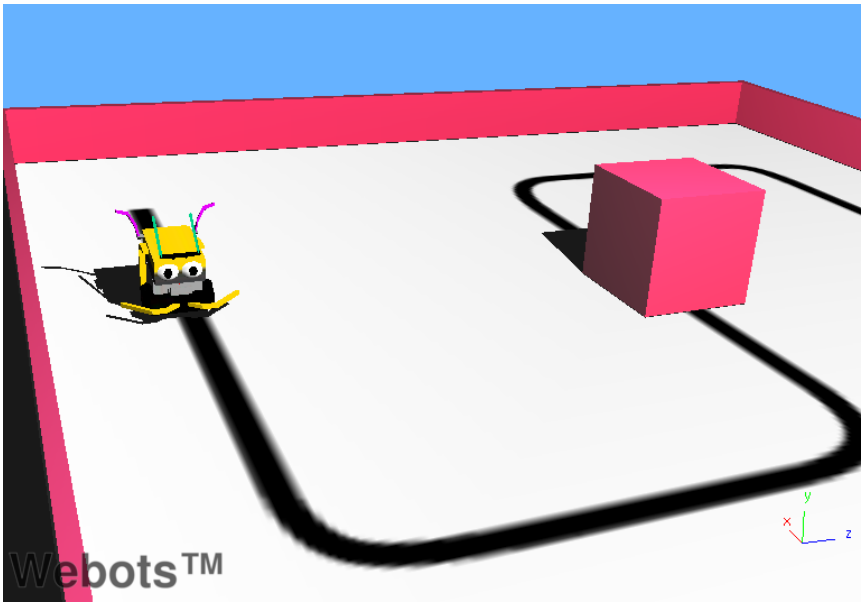


Figure 3.59: rover.wbt

3.5.27 rover.wbt

Keywords: *DifferentialWheels, bumper, TouchSensor, line following, Rover, Java*

In this example you can see the Mindstorms Rover robot from LEGO following a black line drawn on the ground. In the middle of this line there is an obstacle which the robot navigates around after detecting a collision with it. The robot will then recover its path. As this robot is a *Mindstorms* robot, its world file and its controller are in the `mindstorms` directory. This example is written both in Java and C, as a reference for translating Webots code from one language to another. The source code for this controller is in the `Rover` directory.

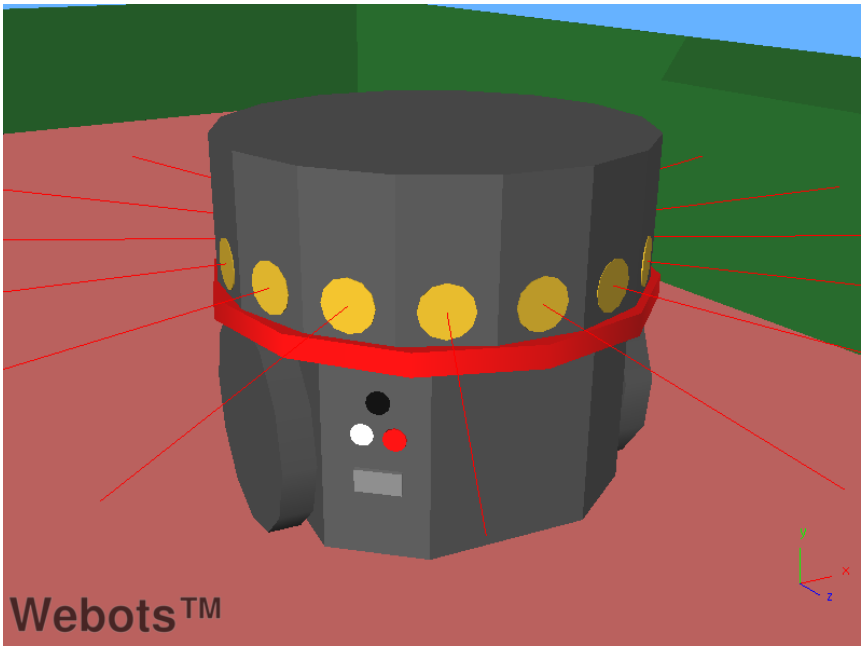


Figure 3.60: scout2.wbt

3.5.28 scout2.wbt

Keywords: *DifferentialWheels, DistanceSensor, Braitenberg, Scout 2*

In this example, a Scout 2 robot moves inside an arena while avoiding the walls. Its world file is in the `others/worlds` directory. Like many other examples, this one uses the braitenberg controller. The source code for this controller is in the `WEBOTS_MODULES_PATH/projects/default/controllers/braitenberg` directory.

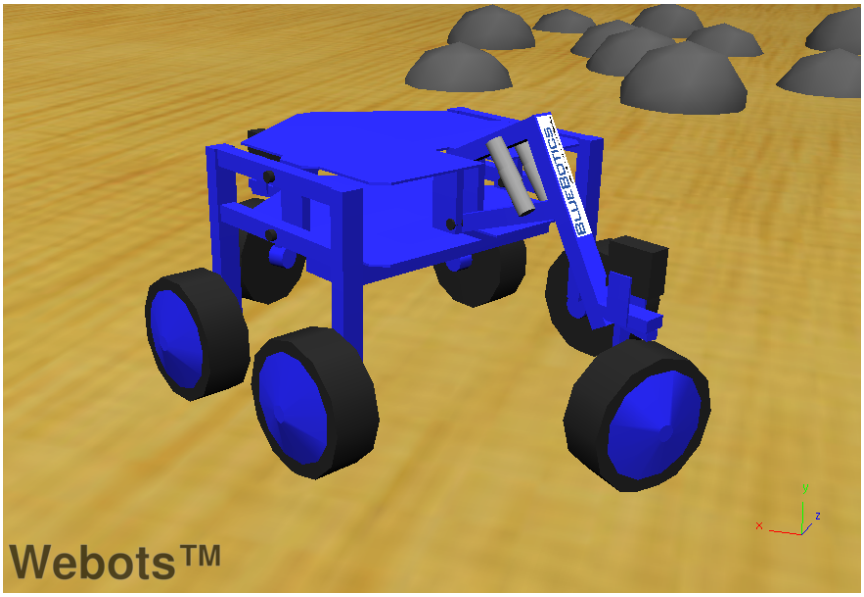


Figure 3.61: shrimp.wbt

3.5.29 shrimp.wbt

Keywords: *Robot node, custom ODE plugin, keyboard, passive joint, uneven ground sponginess, Shrimp, LinearMotor*

This example contains a model of the *Shrimp* robot, which is a mobile platform for rough terrain from Bluebotics[1]. It has 6 wheels and a passive structure which allows it to adapt to the terrain profile and climb obstacles. It can also turn on the spot. In this example the robot will first move on its own to the center of the world; then you may drive it yourself using the keyboard. To find out which keys will allow you to perform these operations, please read the explanation message printed at the beginning of the simulation in the Console window.

Because of its particular structure, this model is also an example of custom ODE plugins for:

- how to create and manage ODE joints
- how to add custom force
- how to create spongy tires

The source code for this controller is in the `WEBOTS_MODULES_PATH/projects/robots/shrimp/controllers/shrimp` directory, and the ODE plugin is in the `WEBOTS_MODULES_PATH/projects/robots/shrimp/plugins/physics/shrimp` directory.

[1] `http://www.bluebotics.ch`

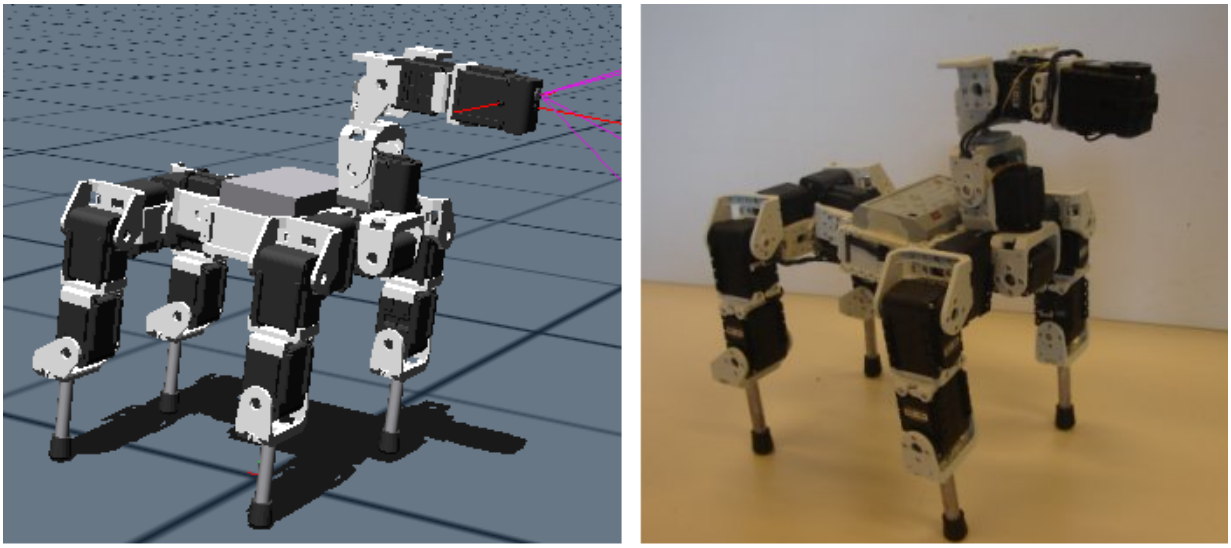


Figure 3.62: bioloid.wbt

3.5.30 bioloid.wbt

Keywords: *Robot node, legged robot, RotationalMotor, Bioloid, Camera, DistanceSensor, keyboard, modular robots, walking*

In this example, the four-legged robot model (figure 3.62 (a)) corresponds to a real Bioloid[2] robot (figure 3.62 (b)) developed by and commercially available from Tribotix[3]. This dog-robot model was build from the Bioloid Comprehensive Kit.

Both the visual aspect and the physical properties of the real robot have been modeled. The physical dimensions, friction coefficients and mass distribution have been estimated after various measurements on the components of the real robot.

The source code for the controller of the robot, as well as the model of the robot are located under the Webots installation directory, in the `WEBOTS_MODULES_PATH/projects/robots/bioloid` sub folder:

- `controllers/bioloid/`: controller directory.
- `worlds/bioloid.wbt`: world definition file containing a Bioloid dog robot.

Using the keyboard, the user can control the quadruped robot by setting the walking direction (forward or backwards) and also the heading direction (right or left). Keyboard actions include:

- Right Arrow: Turn right

[2] `http://www.robotis.com`
[3] `http://www.tribotix.com`

- Left Arrow: Turn left
- B: Walk backwards
- F: Walk forward

The walking gait used in the controller relies on an inverse kinematics model. Further details are available from BIRG web site[4]. The included controller illustrates a trotting gait showing the best performance so far. The turning capabilities of the robot are based on the stride length modulation. When the robot is asked to turn right, the stride length of the right side and left side are respectively decreased and increased. During the walk, the extremity of each leg is describing an ellipsoid, the diameters of these ellipsoids are updated according to the stride length to allow the robot to turn either right or left.

Other keyboard actions are also provided to fine-tune the frequency and the stride length factor:

- Q: Increase frequency
- W: Decrease frequency
- S: Increase stride length factor
- A: Decrease stride length factor

[4] http://birg.epfl.ch/page66584.html

Chapter 4

Language Setup

Webots controllers can be written in C/C++, Java, Python or MATLAB™. This chapter explains how to install the software development kits for the programming language of your choice.

4.1 Introduction

Webots can execute controllers written in compiled (C/C++, Java) or interpreted (Python, MATLAB™) languages. The compilation or interpretation process requires extra software that must usually be installed separately. Only when using C/C++ on the Windows platform it is not necessary to install a separate C/C++ compiler; on this platform Webots comes with a pre-installed and preconfigured copy of the MinGW C/C++ compiler. For any other language or platform the software development tools must be installed separately. Note that Webots uses very standard tools that may already be present in a standard installation. Otherwise the instructions in this chapter will advise you about the installation of your software development tools.

4.2 Controller Start-up

The .wbt file contains the name of the controller that needs to be started for each robot. The controller name is platform and language independent field; for example when a controller name is specified as "xyz_controller" in the .wbt file, this does not say anything about the controller's programming language or platform. This is done deliberately to ensure the platform and programming language independence of .wbt files.

So when Webots tries to start a controller it must first determine what programming language is used by this controller. So, Webots looks in the project's `controllers` directory for a subdirectory that matches the controller name. Then, in this controller directory, it looks for a file that matches the controller name. For example if the controller name is "xyz_controller", then Webots

looks for these files in the specified order, in the `PROJECT_DIRECTORY/controllers/xyz_controller` directory.

1. xyz_controller[.exe] (a binary executable)
2. xyz_controller.class (a Java bytecode class)
3. xyz_controller.jar (a Java .jar file)
4. xyz_controller.bsg (a Webots/BotStudio file)
5. xyz_controller.py (a Python script)
6. xyz_controller.m (a MATLAB™script)

The first file that is found will be executed by Webots using the required language interpreter (java, python, matlab). So the priority is defined by the file extension, e.g. it won't be possible to execute `xyz_controller.m` if a file named `xyz_controller.py` is also present in the same controller directory. In the case that none of the above filenames exist or if the required language interpreter is not found, an error message will be issued and Webots will start the `void` controller instead.

language: Java
In the Java case there are two options. The controller can be placed in a `.class` file or in a `.jar` file. If a `.class` file is used, it must be named `xyz_controller.class`. If a `.jar` file is used it must be named `xyz_controller.jar` and it must contain a class named `xyz_controller` that Webots will attempts to start.

4.3 Using C

4.3.1 Introduction

The C API (Application Programming Interface) is composed of a set of about 200 C functions that can be used in C or C++ controller code. This is the low level interface with the Webots simulator; all other APIs are built over the C API. A majority of Webots controller examples are written in C, therefore the C API is Webots de facto standard API. Although less represented in the controller examples, the other APIs offer exactly the same functionality as the C API.

4.3.2 C/C++ Compiler Installation

Windows Instructions

The Windows version of Webots comes with a pre-installed copy of the MinGW C/C++ compiler, so there is usually no need to install a separate compiler. The MinGW compiler is a port of the GNU Compiler Collection (gcc) on the Windows platform. The advantage of using the MinGW compiler will be the better portability of your controller code. If you develop your code with MinGW it will be straightforward to recompile it on the other Webots supported platforms: Mac OS X and Linux. However, if you prefer using the Visual C++ compiler you will find instructions there.

Mac OS X Instructions

In order to compile C/C++ controllers on the Mac, you will need to install Apple Xcode. Xcode is a suite of tools, developed by Apple, for developing software for Mac OS X. Xcode is free and can be downloaded from the Apple App Store. Webots will need principally the `gcc` (GNU C Compiler) and `make` commands of Xcode. To install these commands, start Xcode and go to Xcode menu, Preferences, Downloads, Components and click **Install** for "Command Line Tools".

Linux Instructions

For compiling C controllers, Webots will need the GNU C Compiler and GNU Make utility. On Linux, these tools are often pre-installed, otherwise you will need to install them separately (*gcc* and *make* packages). For C++ you will also need the GNU C++ Compiler (*g++* package). Optionally you can also install the GNU Debugger (*gdb* package).

4.4 Using C++

4.4.1 Introduction

The C++ API is a wrapper of the C API described in the previous section. The major part of the C functions has been wrapped in a function of a specific class. It is currently composed of a set of about 25 classes having about 200 public functions. The classes are either representations of a node of the scene tree (such as Robot, LED, etc.) or either utility classes (such as Motion, ImageRef, etc.). A complete description of these functions can be found in the reference guide while the instructions about the common way to program a C++ controller can be found in the chapter 6.

4.4.2 C++ Compiler Installation

Please refer to the instructions for the C Compiler installation here.

4.4.3 Source Code of the C++ API

The source code of the C++ API is available in the Webots release. You may be interested in looking through the directory containing the header files (`include/controllers/cpp`) in order to get the precise definition of every classes and functions although the reference guide offers a clean description of the public functions. This directory is automatically included when the C++ controller is compiled.

For users who want to use a third-party development environment, it is useful to know that the shared library (`CppController.dll`, `libCppController.so`, or `libCppController.dylib`) is located in the `lib` subdirectory of your Webots directory. This directory is automatically included when the C++ controller is linked.

For advanced users who want to modify the C++ API, the C++ sources and the Makefile are located in the `resources/languages/cpp` directory.

4.5 Using Java

4.5.1 Introduction

The Java API has been generated from the C++ API by using SWIG. That implies that their class hierarchy, their class names and their function names are almost identical. The Java API is currently composed of a set of about 25 classes having about 200 public functions located in the package called *com.cyberbotics.webots.controller*. The classes are either representations of a node of the scene tree (such as Robot, LED, etc.) or either utility classes (such as Motion, ImageRef, etc.). A complete description of these functions can be found in the reference guide while the instructions about the common way to program a Java controller can be found in the chapter 6.

4.5.2 Java and Java Compiler Installation

In order to develop and run Java controllers for Webots it is necessary to have the Java Development Kit (JDK) version 1.7.

Installation Instructions

The Java Development Kit (JDK) can be downloaded for free from the Sun Developer Network[1]. Make sure you choose the most recent release and the Standard Edition (SE) of the JDK 7. For Windows, make also sure you have selected the 64 bit version since webots is incompatible with the 32 bit version. Then follow the installation instructions attending the package.

The `java` command is the Java Virtual Machine (JVM); it is used for executing Java controllers in Webots. The `javac` command is the Java compiler; it is used for compiling Java controllers in Webots text editor.

These commands should be accessible from a terminal. If it is not the case, this can be done by modifying your *PATH* environment variable.

On Mac the JDK installer should do this automatically.

On Linux, you can set the *PATH* by adding this line to your `~/.bashrc` or equivalent file.

```
$ export PATH=/usr/lib/jvm/java-XXXXXX/bin:$PATH
```

Where *java-XXXXXX* should correspond to the actual name of the installed JDK package.

On Windows, the *PATH* variable must be set using the **Environment Variables** dialog.

On Windows 7 and 8, this dialog can be opened like this: Choose **Start, Settings, Control Panel, System and Security, System** and open **Advanced system settings**. Select the **Advanced** tab and click on the **Environment Variables** button.

In the dialog, in the **User variables for ...** section, look for a variable named *PATH*. Add the `bin` path of the installed SDK to the right end of *PATH* variables. If the *PATH* variable does not exist you should create it. A typical value for *PATH* is:

```
C:\Program Files\Java\jdk-XXXXXX\bin
```

Where *jdk-XXXXXX* stands for the actual name of the installed JDK package.

Then, you need to restart Webots so that the change is taken into account.

Note that the *PATH* can also be set globally for all users. On Linux this can be achieved by adding it in the `/etc/profile` file. On Windows this can be achieved by adding it to the *Path* variable in the **System variables** part of the **Environment Variables** dialog.

Linux and OpenJDK Instructions

In alternative to Oracle JDK, on most popular Linux distribution is also possible to directly install the open-source JDK from the system package manager. Detailed information can be found on the OpenJDK website[2].

[1] `http://www.oracle.com/technetwork/java/javase/downloads`
[2] `http://openjdk.java.net/install/index.html`

Troubleshooting the Java installation

If a Java controller fails to execute or compile, check that the `java`, respectively the `javac` commands are reachable. You can verify this easily by opening a Terminal (Linux and Mac OS X) or a Command Prompt (Windows) and typing `java` or `javac`. If these commands are not reachable from the Terminal (or Command Prompt) they will not be reachable by Webots. In this case check that the JDK is installed and that your *PATH* variable is defined correctly as explained above.

If you run into an error message that looks approximately like this:

```
Native code library failed to load. See the chapter on Dynamic Linking
Problems in the SWIG Java documentation for help.
java.lang.UnsatisfiedLinkError: libJavaController.jnilib: no suitable
image found.
```

this is due to a 32-bit/64-bit incompatibility between Java Virtual Machine (JVM) and Webots. On Mac OS X this problem should disappear after you upgrade to a recent version of Webots (6.3.0 or newer). On Windows, Webots is only compatible with 64-bit versions of Java. On Linux (and Mac OS X) you should be able to solve this problem by replacing the default "java" command string by "java -d32" or "java -d64" in the dialog **Tools** > **Preferences** > **General** > **Java command**.

4.5.3 Link with external jar files

When a Java controller is either compiled or executed, respectively the `java` and the `javac` commands are executed with the `-classpath` option. This option is filled internally with the location of the controller library, the location of the current controller directory, and the content of the *CLASSPATH* environment variable. In order to include third-party jar files, you should define (or modify) this environment variable before running Webots (see the previous section in order to know how to set an environment variable). Under windows, the CLASSPATH seems like this,

```
$ set CLASSPATH=C:\Program Files\java\jdk\bin;relative\mylib.jar
```

while under Linux and Mac OS X, it seems like this:

```
$ export CLASSPATH=/usr/lib/jvm/java/bin:relative/mylib.jar
```

4.5.4 Source Code of the Java API

The source code of the Java API is available in the Webots release. You may be interested in looking through the directory containing the Java files (`resources/languages/java/SWIG_generated_files`) in order to get the precise definition of every classes and functions although these files have been generated by SWIG and are difficult to read.

For users who want to use a third-party development environment, it can be useful to know that the package of the Java API (`Controller.jar`) is located in the `lib` directory.

Advanced users may want to modify the Java API. They will need to modify the SWIG script (controller.i), the java sources and the Makefile located in the `resources/languages/java` directory.

4.6 Using Python

4.6.1 Introduction

The Python API has been generated from the C++ API by using SWIG. That implies that their class hierarchy, their class names and their function names are almost identical. The Python API is currently composed of a set of about 25 classes having about 200 public functions located in the module called *controller*. The classes are either representations of a node of the scene tree (such as Robot, LED, etc.) or either utility classes (such as Motion, ImageRef, etc.). A complete description of these functions can be found in the reference guide while the instructions about the common way to program a Python controller can be found in chapter 6.

4.6.2 Python Installation

Version

The Python API of Webots is built with Python 2.7. Python 2.7 or earlier versions are therefore recommended although more recent versions can work without guarantee. Python 3 is not supported.

Mac OS X and Linux Instructions

Most of the Linux distribution have Python 2.7 already installed. Mac OS X also has Python installed by default. To check the current version of Python installed on your system, you can type in a terminal:

```
$ python --version
```

Webots will start Python using the `python2.7` command line. To check if this command line is installed on your computer, you can type in a terminal:

```
$ python2.7 --version
```

More information is available from the Python official web site[3].

[3] `http://www.python.org/`

Windows Instructions

Webots comes with Python 2.7 64-bit pre-installed in the `msys64` folder.

4.6.3 Source Code of the Python API

For advanced users who want to modify the Python API, the SWIG script (`controller.i`), and the Makefile are located in the `resources/languages/python` directory while the generated library is located in the `lib`.

4.7 Using MATLAB

4.7.1 Introduction to MATLAB™

MATLAB™is a numerical computing environment and an interpreted programming language. MATLAB™allows easy matrix manipulation, plotting of functions and data, implementation of algorithms and creation of user interfaces. You can get more information on the official MathWorks[4] web site. MATLAB™is widely used in robotics in particular for its *Image Processing, Neural Networks* and *Genetics Algorithms* toolboxes. Webots allows to directly use MATLAB™scripts as robot controller programs for your simulations. Using the MATLAB™interface, it becomes easy to visualize controller or supervisor data, for example, processed images, sensor readings, the performance of an optimization algorithm, etc., while the simulation is running. In addition, it becomes possible to reuse your existing MATLAB™code directly in Webots.

4.7.2 How to run the Examples?

If MATLAB™is already installed, you can directly launch one of the MATLAB™examples. For doing that, start Webots and open the world file `WEBOTS_MODULES_PATH/projects/languages/matlab/worlds/e-puck_matlab.wbt` or the world file `WEBOTS_MODULES_PATH/projects/robots/aldebaran/worlds/nao2_matlab.wbt` in your Webots installation directory. Webots automatically starts MATLAB™when it detects an m-file in a controller directory. Note that the m-file must be named after its directory in order to be identified as a controller file by Webots. So, for example, if the directory is named `my_controller`, then the controller m-file must be named `my_controller/my_controller.m`.

No special initialization code is necessary in the controller m-file. In fact Webots calls an intermediate `launcher.m` file that sets up the Webots controller environment and then calls the controller m-file. In particular the `launcher.m` file loads the library for communicating with Webots and adds the path to API m-files. The MATLAB™API m-files are located in the

[4] `http://www.mathworks.com`

lib/matlab directory of Webots distribution. These are readable source files; please report any problem, or possible improvement about these files.

4.7.3 MATLAB™ Installation

In order to use MATLAB™ controllers in Webots, the MATLAB™ software must be installed (The MathWorks™ license required).

Webots must be able to access the matlab executable (usually a script) in order to run controller m-files. Webots looks for the *matlab* executable in every directory of your *PATH* (or *Path* on Windows) environment variable. Note that this is similar to calling matlab from a terminal (or *Command Prompt* on Windows), therefore, if MATLAB™ can be started from a terminal then it can also be started from Webots.

On Windows, the MATLAB™ installer will normally add MATLAB™'s bin directories to your *Path* environment variable, so usually Webots will be able to locate MATLAB™ after a standard installation. However, in case it does not work, please make sure that your *Path* contains this directory (or something slightly different, according to your MATLAB™ version):

```
Path=C:\Program Files\MATLAB\R2009b\bin
```

On Linux, the MATLAB™ installer does normally suggest to add a symlink to the matlab startup script in the /usr/local/bin directory. This is a good option to make matlab globally accessible. Otherwise you can create the link at anytime afterwards with this shell command (please change according to your actual MATLAB™ installation directory and version):

```
$ sudo ln -s /usr/local/MATLAB/R2014a/bin/matlab /usr/local/bin/matlab
```

Similarly, on Mac OS X, if Webots is unable to find the matlab startup script then you should add a symlink in /usr/bin:

```
$ sudo ln -s /Applications/MATLAB_R2014a.app/bin/matlab /usr/bin/
   matlab
```

4.7.4 Display information to Webots console

On Linux and Mac OS X, the Matlab output is redirected as is to the Webots console. This means you can use all the Matlab display features (disp(), display(), omitting the semicolon character at the end of a statement, etc.).

On Windows, the Matlab output is not redirected to the Webots console. The wb_console_print(text, stream) function should be used to display some text in the Webots console. The second argument (stream) can be either WB_STDOUT or WB_STDERR depending on which stream you would like to write.

In order to create a cross-platform controller, it is recommended to use the wb_console_print(text, stream) on every OS.

4.7.5 Compatibility Issues

We recommend to use the latest Matlab version on an up-to-date operating system.

Note that 64-bit versions of Webots are not compatible with 32-bit versions of MATLAB™. Webots comes only in 64-bit flavour and therefore it can only inter-operate with a 64 bit version of MATLAB™.

On some platform the MATLAB™interface needs `perl` and `gcc` to be installed separately. These tools are required because MATLAB™'s `loadlibrary()` function will need to re-compile Webots header files on the fly. According to MATLAB™'s documentation this will be the case on 64-bit systems, and hence we advice 64-bit Webots users (on Linux) to make sure that these packages are installed on their systems.

On some Mac OS X systems the MATLAB™interface will work only if you install the Xcode development environment, because `gcc` is required. An error message like this one, is a symptom of the above described problem:

```
error using ==> calllib
Method was not found.

error in ==> launcher at 66
calllib('libController','wb_robot_init');
```

4.8 Using ROS

4.8.1 What is ROS?

ROS[5] (Robot Operating System) is a framework for robot software development, providing operating system-like functionality on top of a heterogenous computer cluster. ROS was originally developed in 2007 by the Stanford Artificial Intelligence Laboratory. As of 2008, development continues primarily at Willow Garage[6].

ROS provides standard operating system services such as hardware abstraction, low-level device control, implementation of commonly-used functionality, message-passing between processes, and package management. It is based on a graph architecture where processing takes place in nodes that may receive, post and multiplex sensor, control, state, planning, actuator and other messages. The library is geared towards a Unix-like system and is supported under Linux, experimental on Mac OS X and has partial functionality under Windows.

ROS has two basic "sides": The operating system side, ros, as described above and ros-pkg, a suite of user contributed packages (organized into sets called stacks) that implement functionality such as simultaneous localization and mapping, planning, perception, simulation etc.

[5] `http://www.ros.org/`
[6] `http://www.willowgarage.com/`

ROS is released under the terms of the BSD license, and is open source software. It is free for commercial and research use. The ros-pkg contributed packages are licensed under a variety of open source licenses.

4.8.2 ROS for Webots

There are two ways to use ROS with Webots. The first solution and the easiest one is to use the standard ROS controller. It is part of the Webots default controllers and is available in any project. This controller can be used on any robot in Webots and acts as a ROS node, providing all the Webots functions as services or topics to other ROS nodes. The second custom and more complicated solution is to build your own Webots controller that will also be a ROS node using Webots and ROS libraries. This solution should only be used for specific application that cannot be done with the standard controller.

Standard Controller

This controller uses the `libCppController` library and proposes the available Webots functionalities on the ROS network according to the robot's configuration. Using the `roscpp` library, it provides these Webots functions mostly as ROS services and uses standard messages type to avoid dependencies on third-party packages.

During simulation there can be multiple instances of robots or devices and other Webots applications connected to the ROS network. Therefore the controller uses a specific syntax to declare its services or topics on the network:

`[robot_unique_name]/[device_name]/[service/topic_name]`

`[robot_unique_name]`: in order to avoid any misunderstanding between different instances of the same robot, the name of the robot is followed by the ID of the process and the IP address of the computer.

`[device_name]`: since the same function can refer to different devices, this field show you which device it refers to.

`[service/topic_name]`: this field is equal or really close to the Webots function it corresponds. For topics, it is followed by the sampling period. For services, it is also the name of the corresponding srv file.

Using the Standard Controller

The controller is pre-compiled and you shouldn't edit it. All you have to do is to load it on your robot; you will find it in the default list of controller. In order to use it, you will have to build a ROS node that will communicates with the robot using the different services available. Good examples of such ROS node can be found inside Webots at `WEBOTS_MODULES_PATH/`

`projects/languages/ros/nodes`. In this folder you will find useful instructions to help you.

*If you wants to access the controller from another machine and the roscore isn't running on the same machine as Webots, you will need to edit the ROS_MASTER_URI variable. This can be done by editing your environment variables, adding the address in the controller arguments in Webots or with a runtime.ini file in the controller directory. You must also be able to connect to each of the computer in ssh in both ways. As ROS uses the hostname to find other computer/devices on the network, you must had other computers' hostname and the associated IP address to the known hosts of each computer. You can find this list in a file named *hosts*. On Linux distribution, you can find it directly at /etc/hosts; on Mac OS X, it is located at /private/etc/hosts; on Windows, it is located at C:\Windows\System32\drivers\etc\hosts. On Windows and Mac OS X, this a hidden path and you will need to search directly for this path. The hosts file is usually protected and you will need administrator or root right to edit it.*

Custom Controller

The standard controller has been developed in order to work on every robot and for general purpose. Sometimes, you may not be able to do what you want with this controller or it would be too complicated. In this case, you can build your own custom controller and ROS node.

It is possible to implement such a ROS node in C++ using the `roscpp` library. However, in this case, you need to setup a build configuration to handle both the `catkin_make` from ROS and the `Makefile` from Webots to have the resulting binary linked both against the Webots `libController` and the `roscpp` library. An example of such an implementation is included in the Webots distribution (see below).

This controller can also be implemented in Python by importing both ROS libraries (roslib, rospy) and Webots libraries (controller) in a Webots robot or supervisor controller.

Using the Custom Controller

A sample C++ ROS node running as a Webots controller is provided in the Webots distribution for Linux. It is located in the Webots `WEBOTS_MODULES_PATH/projects/languages/ros/custom` folder and contains a world file named `joystick.wbt` and a controller named `joystick` which allows the user to drive a simulated robot using a joystick through the ROS joy node. This controller is a very simple example of a ROS node running as a Webots controller. It could be used as a starting point to develop more complex interfaces between Webots and ROS. The controller directory includes all the `Makefile` machinery to call the build tools used by

ROS and Webots to produce the controller binary. The `ros` folder also includes a `README.txt` file with detailed installation and usage instructions.

Following the instructions `README.md` is necessary to make the joystick example work on your Linux system.
In the `Tutorials` chapter, you will find a section explaining how to rebuild from scratch the joystick example.

4.9 Interfacing Webots to third party software with TCP/IP

4.9.1 Overview

Webots offers programming APIs for following languages: C/C++, Java, Python and MATLAB™. It is also possible to interface Webots with other programming languages of software packages, such as Lisp™, LabView™, etc. Such an interface can be implemented through a TCP/IP protocol that you can define yourself. Webots comes with an example of interfacing a simulated Khepera robot via TCP/IP to any third party program able to read from and write to a TCP/IP connection. This example world is called `khepera_tcpip.wbt`, and can be found in the `WEBOTS_MODULES_PATH/projects/robots/khepera/khepera1/worlds` directory of Webots. The simulated Khepera robot is controlled by the `tcpip` controller which is in the `controllers` directory of the same project. This small C controller comes with full source code in `tcpip.c`, so that you can modify it to suit your needs. A client example is provided in `client.c`. This client may be used as a model to write a similar client using the programming language of your third party software. This has already been implemented in Lisp™and MATLAB™by some Webots users.

4.9.2 Main advantages

There are several advantages of using such an interface. First, you can have several simulated robots in the same world using several instances of the same `tcpip` controller, each using a different TCP/IP port, thus allowing your third party software to control several robots through several TCP/IP connections. To allow the `tcpip` process to open a different port depending on the controlled robot, you should give a different `name` to each robot and use the `robot_get_name()` in the `tcpip` controller to retrieve this name and decide which port to open for each robot.

The second advantage is that you can also control a real robot from your third party software by simply implementing your library based on the given remote control library. Switching to the remote control mode will redirect the input/output to the real robot through the Inter-Process Communication (IPC). An example of remote control is implemented for the e-puck robot in the file

WEBOTS_MODULES_PATH/projects/robots/e-puck/worlds/e-puck.wbt directory of Webots.

The third advantage is that you can spread your controller programs over a network of computers. This is especially useful if the controller programs perform computationally expensive algorithms such as genetic algorithms or other learning techniques.

Finally, you should set the controlled robot to synchronous or asynchronous mode depending on whether or not you want the Webots simulator to wait for commands from your controllers. In synchronous mode (with the synchronization field of the robot equal to TRUE), the simulator will wait for commands from your controllers. The controller step defined by the robot_step parameter of the tcpip controller will be respected. In asynchronous mode (with the synchronization field of the robot set to FALSE), the simulator will run as fast as possible, without waiting for commands from your controllers. In the latter case, you may want to run the simulation in real time mode so that robots will behave like real robots controlled through an asynchronous connection.

4.9.3 Limitations

The main drawback of TCP/IP interfacing is that if your robot has a camera device, the protocol must send the images to the controller via TCP/IP, which might be network intensive. Hence it is recommended to have a high speed network, or use small resolution camera images, or compress the image data before sending it to the controller. This overhead is negligible if you use a low resolution camera such as the Khepera K213 (see example WEBOTS_MODULES_PATH/projects/robots/khepera/khepera1/worlds/khepera_k213.wbt).

Chapter 5

Development Environments

This chapter indicates how to use the built-in development environment or third-party environments for developing Webots controllers.

5.1 Webots Built-in Editor

Webots source code editor is a multi-tab text editor specially adapted for developing Webots controllers. It is usually recommended to use this editor as it makes the compilation straightforward. The editor features syntax highlighting for Webots supported language (C/C++, Java, Python and MATLAB™) and auto-completion for Webots C API.

5.1.1 Compiling with the Source Code Editor

The Source Code Editor can be used to compile C/C++ or Java source files into binary executable or bytecode (Java) files that can be executed in a simulation. The compilation output is printed to Webots console; errors and warnings appear in red. If you double-click an error message, Webots will highlight the corresponding source line in the editor.

Note that, for compiling source code it is necessary to have the appropriate development tools installed. You will find information on the development tools `here`.

In the following, the possible compilation actions are listed. Some of them are only accessible in the **Build** menu, whereas **Build** and **Clean** actions have a shortcut in the Text Editor toolbar.

Builds the whole project by invoking `make` in the selected file's directory. With C/C++, the **Build** button compiles and links the whole project into an executable file. C/C++ source file dependencies are automatically generated and updated when necessary. With Java, the **Build** button compiles the whole project into bytecode (.class files).

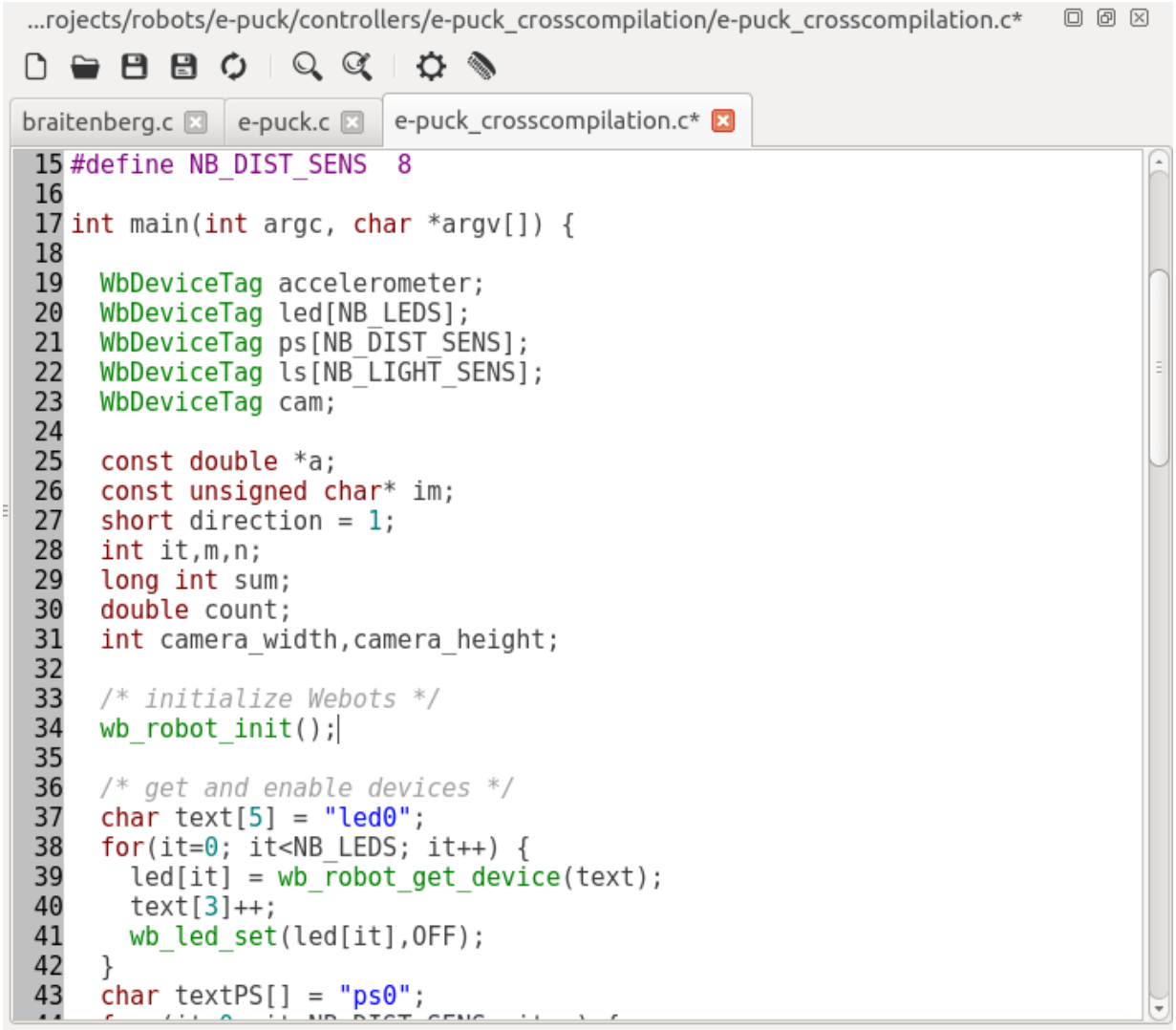


Figure 5.1: Webots Text Editor

The **Clean** button invokes `make clean` to delete the intermediate compilation files in the current file's directory. The source files remain untouched.

The **Make JAR file** menu item rebuilds the whole project and packs all the .class in a `.jar`. This is a convenience function that can be used to pack a complete controller prior to uploading it to one of our online contest website.

The **Cross-compile** menu item allows to cross-compile the current text editor's file. Note that a specific Makefile is required in the controller's directory for performing this operation. For an e-puck robot, this Makefile must be named `Makefile.e-puck`.

The **Cross-compilation clean** menu item allows you to clean the cross-compilation files. Note that a specific Makefile is required in the controller's directory for performing this operation. For an e-puck robot, this Makefile must be named `Makefile.e-puck`.

5.2 The standard File Hierarchy of a Project

Some rules have to be followed in order to create a project which can be used by Webots. This section describes the file hierarchy of a simple project.

5.2.1 The Root Directory of a Project

The root directory of a project contains at least a directory called `worlds` containing a single world file. But several other directories are often required:

- `controllers`: this directory contains the controllers available in each world files of the current project. The link between the world files and this directory is done through the *controller* field of the *Robot* node (explained in the reference manual). More information about this directory in the following subsections.
- `protos`: this directory contains the PROTO files available for all the world files of the current project.
- `plugins`: this directory contains the plugins available in the current project. The link between the world files and this directory is done through the *physics* field of the *WordInfo* node (explained in the reference manual).
- `worlds`: this directory contains the world files, the project files (see below) and the textures (typically in a subdirectory called `textures`).

Note that the directories can be created by using the wizard `New Project Directory` *described in chapter 2.*

5.2.2 The Project Files

The project files contain information about the GUI (such as the perspective). These files are hidden. Each world file can have one project file. If the world file is named `myWorldFile.wbt`, its project file is named `.myWorldFile.wbproj`. This file is written by Webots when a world is correctly closed. Removing it allows you to retrieve the default perspective.

5.2.3 The "controllers" Directory

This directory contains the controllers. Each controller is defined in a directory. A controller is referenced by the name of the directory. Here is an example of the controllers directory having one simple controller written in C which can be edited and executed.

```
controllers/
controllers/simple_controller/
controllers/simple_controller/Makefile
controllers/simple_controller/simple_controller.c
controllers/simple_controller/simple_controller[.exe]
```

The main executable name must be identical to the directory name.

You can create all the files needed by a new controller using the wizard `New Robot Controller` *described in chapter 2.*

5.3 Compiling Controllers in a Terminal

It is possible to compile Webots controllers in a terminal instead of the built-in editor. In this case you need to define the `WEBOTS_HOME` environment variable and make it point to Webots installation directory. The `WEBOTS_HOME` variable is used to locate Webots header files and libraries in the Makefiles. Setting an environment variable depends on the platform (and shell), here are some examples:

5.3.1 Mac OS X and Linux

These examples assume that Webots is installed in the default directory. On Linux, type this:

```
$ export WEBOTS_HOME=/usr/local/webots
```

or add this line to your `~/.bash_profile` file. On Mac OS X, type this:

```
$ export WEBOTS_HOME=/Applications/Webots
```

or add this line to your `~/.profile` file.

Once `WEBOTS_HOME` is defined, you should be able to compile in a terminal, with the `make` command. Like with the editor buttons, it is possible to build the whole project, or only a single binary file, e.g.:

```
$ make
$ make clean
$ make my_robot.class
$ make my_robot.o
```

5.3.2 Windows

On Windows you must use the MSYS terminal to compile the controllers. MSYS is a UNIX-like terminal that can be used to invoke MinGW commands. It can be downloaded from http://sourceforge.net[1]. You will also need to add the `bin` directory of MinGW to your *PATH* environment variable. MinGW is located in the `mingw` subdirectory of Webots distribution. When set correctly, the environment variable should be like this:

```
WEBOTS_HOME=C:\Program Files\Webots
PATH=C:\program Files\Webots\mingw\bin;C:\...
```

Once MSYS is installed and the environment variables are defined, you should be able to compile controllers by invoking `mingw32-make` in the MSYS terminal, e.g.:

```
$ mingw32-make
$ mingw32-make clean
$ mingw32-make my_robot.class
$ mingw32-make my_robot.o
```

5.4 Using Webots Makefiles

5.4.1 What are Makefiles

The compilation of Webots C/C++ and Java controllers can be configured in the provided Makefiles. A controller's Makefile is a configuration file used by the `make` utility and that optionally

[1] `http://sourceforge.net`

specifies a list of source files and how they will be compiled and linked to create the executable program.

Note that Python and MATLAB™are interpreted languages and therefore they don't need Makefiles. So if you are using any of these programming languages or Visual C++ then you can ignore this section.

When using C/C++ or Java, the presence of a Makefile in the controller directory is necessary. If the Makefile is missing Webots will automatically propose to create one. This Makefile can be modified with a text editor; its purpose is to define project specific variables and to include the global `Makefile.include` file. The global `Makefile.include` file is stored in `WEBOTS_HOME/resources/` directory; it contains the effective build rules and may vary with the Webots version. Note that Webots Makefiles are platform and language independent.

5.4.2 Controller with Several Source Files (C/C++)

If a controller requires several C/C++ source files they need to be specified in the Makefile. The name of each source file must be listed, using one of these variables:

Variable	Usage
C_SOURCES	Specifies a list of .c sources files
CXX_SOURCES	Specifies a list of .cpp, *.cc or *.c++ source files

Table 5.1: Webots Makefile Variables

Every source file specified using these variables, will be added to the controller build. In addition dependency files will be automatically generated by the `make` command in order to minimize the build. Note that these variables should not be used in any language other than C or C++.

For example, if a controller has several `.c` source files, then this can be specified like this in the controller's Makefile:

```
C_SOURCES = my_controller.c my_second_file.c my_third_file.c
```

If a project has several `.cpp` source files, then this can be specified like this:

```
CXX_SOURCES = my_controller.cpp my_second_file.cpp my_third_file.cc
```

Important: the build rules require that one of the source files in the list must correspond to the controller name (i.e. controller directory name), e.g. if the controller directory is `my_controller` then the list must contain either `my_controller.c`, `my_controller.cpp` or `my_controller.cc` accordingly.

5.4.3 Using the Compiler and Linker Flags (C/C++)

These two variables can be used to pass flags to the gcc compiler or linker.

Variable	Usage
CFLAGS	Specifies a list of flags that will be passed to the gcc/g++ compiler
INCLUDE	Specifies a list of flags that will be passed to the gcc/g++ compiler
LIBRARIES	Specifies a list of flags that will be passed to the linker

Table 5.2: Webots Makefile Variables

Adding an External Library (C/C++)

Webots C/C++ controllers are regular binary executable files that can easily be compiled and linked with external libraries. To add an external library it is only necessary to specify the path to the header files, and the path and name of the library in the controller's Makefile. For example the `-I`*dir* flag can be used to add a directory to search for include files. The LIBRARIES variable can be used to pass flags to the linker. For example the `-L`*dir* flag can be used to add a directory to search for static or dynamic libraries, and the `-l` flag can be used to specify the name of a library that needs to be linked with the controller.

For example, let's assume that you would like to add an external library called *XYZLib*. And let's assume that the library's header files and `.dll` file are located like this (Windows):

```
C:\Users\YourName\XYZLib\include\XYZLib.h
C:\Users\YourName\XYZLib\lib\XYZLib.dll
```

Then here is how this should be specified in the Makefile:

```
INCLUDE = -I"C:\Users\YourName\XYZLib\include"
LIBRARIES = -L"C:\Users\YourName\XYZLib\lib" -lXYZLib
```

The first line tells gcc where to look for the *#include<XYZLib.h>* file. The second line tells gcc to link the executable controller with the `XYZLib.dll` and where that `.dll` can be found. Note that this would be similar on Linux and Mac OS X, you would just need to use UNIX-compatible paths instead. If more external libraries are required, it is always possible to use additional `-I`, `-L` and `-l` flags. For more information on these flags, please refer to the `gcc` man page.

Using Webots C API in a C++ Controller

Normally, C++ controllers use Webots C++ API. The C++ API is a set of C++ classes provided by C++ header files, e.g. `#include <webots/Robot.hpp>`. If you prefer, C++ controllers can use Webots C API instead. The C API is a set of C functions starting with the `wb` prefix and provided by C header files, e.g. `#include <webots/robot.h>`. To use the C API in a C++ controller you need to add this line in your controller Makefile:

```
USE_C_API = true
```

Adding Debug Information

If you need to debug your controller, you need to recompile it with the `debug` target from a terminal:

```
make debug
```

This will instruct gcc to add debugging information so that the executable can be debugged using gcc.

5.5 Debugging C/C++ Controllers

5.5.1 Controller processes

In the Webots environment, the Webots application and each robot C/C++ controller are executed in distinct operating system processes. For example, when the `soccer.wbt` world is executed, there is a total of eight processes in memory; one for Webots, six for the six player robots, and one for the supervisor. To debug a C/C++ controller with Visual C++, please see here.

When a controller process performs an illegal instruction, it is terminated by the operating system while the Webots process and the other controller processes remain active. Although Webots is still active, the simulation blocks because it waits for data from the terminated controller. So if you come across a situation where your simulation stops unexpectedly, but the Webots GUI is still responsive, this usually indicates the crash of a controller. This can easily be confirmed by listing the active processes at this moment: For example on Linux, type:

```
$ ps -e
...
12751 pts/1    00:00:16 webots
13294 pts/1    00:00:00 soccer_player
13296 pts/1    00:00:00 soccer_player
13297 pts/1    00:00:00 soccer_player
13298 pts/1    00:00:00 soccer_player
13299 pts/1    00:00:00 soccer_player
13300 pts/1    00:00:00 soccer_player
13301 pts/1    00:00:00 soccer_supervisor <defunct>
...
```

On Mac OS X, use rather `ps -x` and on Windows use the *Task Manager* for this. If one of your robot controllers is missing in the list (or appearing as *<defunct>*) this confirms that it has crashed and therefore blocked the simulation. In this example the `soccer_supervisor` has crashed. Note that the crash of a controller is almost certainly caused by an error in the controller code, because an error in Webots would have caused Webots to crash. Fortunately, the GNU debugger (`gdb`) can usually help finding the reason of the crash. The following example assumes that there is a problem with the `soccer_supervisor` controller and indicates how to proceed with the debugging.

5.5.2 Using the GNU debugger with a controller

The first step is to recompile the controller code with the *-g* flag, in order to add debugging information to the executable file. This can be achieved by adding this line to the controller's Makefile:

```
CFLAGS = -g
```

Then you must recompile the controller, either by using the **Clean** and **Build** buttons of the Webots text editor or directly in a terminal:

```
$ make clean
$ make
...
```

Note that, the *-g* flag should now appear in the compilation line. Once you have recompiled the controller, hit the **Pause** and **Revert** buttons. This pauses the simulation and reloads the freshly compiled versions of the controller. Now find the process ID (PID) of the `soccer_supervisor` process, using `ps -e` (Linux) or `ps -x` (Mac OS X), or using the *Task Manager* (Windows). The PID is in the left-most column of output of `ps` as shown above. Then open a terminal and start the debugger by typing:

```
$ gdb
...
(gdb) attach PID
...
(gdb) cont
Continuing.
```

Where PID stands for the PID of the `soccer_supervisor` process. The `attach` command will attach the debugger to the `soccer_supervisor` process and interrupt its execution. Then the `cont` command will instruct the debugger to resume the execution of the process. (On Windows you will need to install the `gdb.exe` file separately and use an MSYS console to achieve this.)

Then hit the **Run** button to start the simulation and let it run until the controller crashes again. The controller's execution can be interrupted at any time (Ctrl-C), in order to query variables, set up break points, etc. When the crash occurs, `gdb` prints a diagnostic message similar to this:

```
Program received signal SIGSEGV, Segmentation fault.
[Switching to Thread -1208314144 (LWP 16448)]
0x00cd6dd5 in _IO_str_overflow_internal () from /lib/tls/libc.so.6
```

This indicates the location of the problem. You can examine the call stack more precisely by using the `where` command of `gdb`. For example type:

```
(gdb) where
#0 0x00cd6dd5 in _IO_str_overflow_internal() from /lib/tls/libc.so.6
#1 0x00cd596f in _IO_default_xsputn_internal() from /lib/tls/libc.so.6
```

```
#2 0x00cca9c1 in _IO_padn_internal() from /lib/tls/libc.so.6
#3 0x00cb17ea in vfprintf() from /lib/tls/libc.so.6
#4 0x00ccb9cb in vsprintf() from /lib/tls/libc.so.6
#5 0x00cb8d4b in sprintf() from /lib/tls/libc.so.6
#6 0x08048972 in run(ms=0) at soccer_supervisor.c:106
#7 0x08048b0a in main() at soccer_supervisor.c:140
```

By examining carefully the call stack you can locate the source of the error. In this example we will assume that the `sprintf()` function is OK, because it is in a system library. Therefore it seems that the problem is caused by an illegal use of the `sprintf()` function in the `run()` function. The line 106 of the source file `soccer_supervisor.c` must be examined closely. While the controller is still in memory you can query the values of some variables in order to understand what happened. For example, you can use the `frame` and `print` commands:

```
(gdb) frame 6
#6  0x08048953 in run (ms=0) at soccer_supervisor.c:106
106         sprintf(time_string, "%02d:%02d", (int) (time / 60),
 (int) time % 60);
(gdb) print time_string
$1 = 0x0
```

The `frame` command instructs the debugger to select the specified stack frame, and the `print` command prints the current value of an expression. In this simple example we clearly see that the problem is caused by a NULL (0x0) *time_string* argument passed to the `sprintf()` function. The next steps are to: fix the problem, recompile the controller and revert the simulation to give it another try. Once it works correctly you can remove the *-g* flag from the Makefile.

5.6 Using Visual C++ with Webots

5.6.1 Introduction

Microsoft Visual C++ is an integrated development environment (IDE) for C/C++ available on the Windows platform. On Windows, Visual C++ is a possible alternative to using Webots built-in gcc (MinGW) compiler. Visual C++ can be used to develop controllers using Webots C or C++ API. The developer must choose one of these two APIs as they cannot be used together in controller code. The C API is composed of `.h` files that contains flat C functions that can be used in C or C++ controllers. The C++ API is composed of `.hpp` files that contain C++ classes and methods that can be used in C++ controllers only.

Two Visual C++ projects examples are included in Webots distribution: `WEBOTS_MODULES_PATH\projects\robots\khr-2hv\controllers\khr2\khr2.vcproj` and `WEBOTS_MODULES_PATH\projects\robots\khr-2hv\plugins\physics\khr2\physics.vcproj`. However in principle any C or C++ controller from Webots distribution can be turned into a Visual C++ project.

5.6.2 Configuration

When creating a Webots controller with Visual C++, it is necessary to specify the path to Webots `.h` and/or `.hpp` files. It is also necessary to configure the linker to use the `Controller.lib` import library from Webots distribution. The `Controller.lib` files is needed to link with the `Controller.dll` file that must be used by the controller in order to communicate with Webots.

The following procedure (Visual C++ 2008 Express) explains how to create a Visual C++ controller for Webots. Note that the resulting `.exe` file must be launched by Webots; it cannot be run from Visual C++.

1. Copy a Webots project from Webots distribution to your `Documents` folder, or create an empty project directory using Webots menu: **Wizard** > **New Project Directory...** Either way, the project directory must contain the `controllers` and `worlds` subdirectories.

2. Start Visual C++ and select: **File** > **New** > **Project...** Then choose these settings:

   ```
   Project type: General
   Template: Empty Project
   Name: MyController (for example)
   Location: C:\Users\MyName\Documents\MyProject\controllers (for
      example)
   ```

   Where "MyController" is the name of a new or already existing controller directory, and where "Location" must indicate the `controllers` subdirectory of your Webots project directory.

3. Then you can add a C or C++ source file to your project: Choose either: **Project** > **Add Existing Item** or **Project** > **Add New Item** > **C++ File (.cpp)**. In the second case you can copy the content of one of the C/C++ examples of Webots distribution.

   Note that if you copied C code from Webots examples to Visual C++, it is highly recommended to change the source file extension from .c to .cpp. The reason is that Webots examples are written for the gcc compiler which uses a more modern version of the C language than Visual C++. By changing the file extension to .cpp you will instruct Visual C++ to compile the file in C++ mode (/TP) which is more tolerant with gcc code. If you don't do it, you may run into error messages like these:

   ```
   MyController.c(24): error C2275: 'WbDeviceTag' : illegal use of
     this type as an expression
   MyController.c(24): error C2146: syntax error : missing ';'
      before
     identifier 'ir0'
   ...
   ```

4. Now we can set up the project configuration for Webots. Select the **Project** > **Properties** menu. In the **Property Pages**, in the **Configuration Properties**, enter following configuration:

   ```
   C/C++ > General > Additional Include Directories:
     C:\Program Files\Webots\include\controller\c
   ```

   This will tell Visual C++ where to find Webots C API (.h files).

   By default Visual C++ places the .exe file in a `Debug` or `Release` subdirectory. However order to be executed by Webots, the .exe file must be placed directly at the root of the `MyController` directory. So in this example the .exe should be there: `MyProject\controllers\MyController\MyController.exe`. Consequently the linker output file should be configured like this:

   ```
   Linker > General > Output File: $(ProjectName).exe
   ```

   Now we need to tell Visual C++ to use the `Controller.lib` import library:

   ```
   Linker > Input > Additional Dependencies:
     Controller.lib
   Linker > General > Additional Library Directories:
     C:\Program Files\Webots\lib
   ```

5. If you want to use the C API, you should skip step 5 and go directly to step 6. If you want to use the C++ API follow these instructions:

   In **Property Pages**, in the **Configuration Properties**, add the path to Webots .hpp files:

   ```
   C/C++ > General > Additional Include Directories:
     C:\Program Files\Webots\include\controller\c
     C:\Program Files\Webots\include\controller\cpp
   ```

   Now you should have the path to both the .h and the .hpp files.

   Then you need to add Webots C++ wrappers to your project. The C++ wrappers are .cpp files that implement the interface between the C++ API and the C API. You can proceed like this:

   In Visual C++, in the **Solution Explorer**: right-mouse-click on the **Sources Files** folder, then select **Add** > **New Filter**. This should create a **NewFilter1** subfolder in your **Sources Files** folder. Then select the **NewFilter1** and with the right-mouse-button: choose the **Add** > **Existing Item...** menu. In the file dialog, go to the `C:\ProgramFiles\Webots\resources\languages\cpp` directory, then select all the .cpp files (but no other file) in that directory and hit the **Add** button. This should add the `Accelerometer.cpp`, `Camera.cpp`, `Compass.cpp`, etc. source files to your project.

6. Now you should be able to build your controller with the **Build** > **Build MyController** menu item (or the F7 key). This should generate the `MyProject\controllers\MyController\MyController.exe` file.

7. Now we can switch to Webots in order to test the .exe controller. Start Webots and verify that your robot is associated with the correct controller: In the **Scene tree**, expand the robot node and check the `controller` field. It should be: `controller "MyController"`. Otherwise you should change it: hit the **...** (ellipsis) button, this opens a selection dialog. In the selection dialog choose "MyController". Then hit the **Save** button in Webots main window. Finally you can hit the **Run** button to start the simulation. At this point the simulation should be using your Visual C++ controller.

8. If you want to debug your controller with Visual C++ you can *attach* the debugger to the running controller process. Proceed like this: In Webots, hit the **Pause** button then the **Revert** button. Then, in Visual C++, use the **Debug** > **Attach to Process...** menu. In the dialog choose the **MyController.exe_webots** process. Still in Visual C++, you can now add breakpoints and watches in the controller code. Then, in Webots, hit the **Run** button to resume the simulation. Now the controller should pause when it reaches one of your breakpoints.

5.7 Starting Webots Remotely (ssh)

Webots can be started on a remote computer, by using `ssh` (or a similar) command. However, Webots will work only if it can get a X11 connection to a X-server running locally (on the same computer). It is currently not possible to redirect Webots graphical output to another computer.

5.7.1 Using the ssh command

Here is the usual way to start from computer A, a Webots instance that will run on computer B:

```
$ ssh myname@computerB.org
$ export DISPLAY=:0.0
$ webots --mode=fast --stdout --stderr myworld.wbt
```

The first line logs onto computer B. The 2nd line sets the DISPLAY variable to the display 0 (and screen 0) of computer B. This will indicate to all X11 applications (including Webots) that they needs to connect to the X-server running on the local computer: computer B in this case. This step is necessary because the DISPLAY variable is usually not set in an `ssh` session.

The last line starts Webots: the *–mode=fast* option enables the *Fast* simulation mode, which is available only with Webots PRO. The *–mode=fast* option makes the simulation run as fast as possible, without graphical rendering, which is fine because the graphical output won't be visible anyway from computer A. Options *–stdout* and *–stderr* are used to redirect Webots' output to the standard streams instead of Webots console, otherwise the output would not be visible on computer A.

At this point, Webots will start only if a X-server with proper authorizations is running on computer B. To ensure that this is the case, the simplest solution is to have an open login session on

computer B, i.e., to have logged in using the login screen of computer B, and not having logged out. Unless configured differently, the `ssh` login and the screen login session must belong to the same user, otherwise the X-server will reject the connection. Note that the `xhost +` command can be used to grant access to the X-server to another user. For security reasons, the screen of the open session on computer B can be locked (e.g. with a screen-saver): this won't affect the running X-server.

5.7.2 Terminating the ssh session

A little problem with the above approach is that closing the `ssh` session will kill the remote jobs, including Webots. Fortunately it is easy to overcome this problem by starting the Webots as a background job and redirecting its output to a file:

```
$ ssh myname@computerB.org
$ export DISPLAY=:0.0
$ webots --mode=fast --stdout --stderr myworld.wbt &> out.txt &
$ exit
```

The &> sign redirects into a text file the output that would otherwise appear in the `ssh` terminal. The & sign starts Webots as a background job: so the user can safely exit the `ssh` session, while Webots keeps running.

In this case the decision to terminate the job is usually made in the Supervisor code according to simulation specific criteria. The `wb_supervisor_simulation_quit()` function can be used to automatically terminate Webots when the job is over.

5.8 Transfer to your own robot

In mobile robot simulation, it is often useful to transfer the results onto real mobile robots. Webots was designed with this transfer capability in mind. The simulation is as realistic as possible, and the programming interface can be ported or interfaced to existing, real robots. Webots already comprises transfer systems for a number of existing robots including e-puck™, DARwIn-OP™, Khepera™and Hemisson™. This section explains how to develop your own transfer system to your own mobile robot.

Since the simulation is only an approximation of the physics of the real robot, some tuning is always necessary when developing a transfer mechanism for a real robot. This tuning will affect the simulated model so that it better matches the behavior of the real robot.

5.8.1 Remote control

Overview

Often, the easiest way to transfer your control program to a real robot is to develop a remote control system. In this case, your control program runs on the computer, but instead of sending commands to and reading sensor data from the simulated robot, it sends commands to and reads sensor data from the real robot. Developing such a remote control system can be achieved in a very simple way by writing your own implementation of the Webots API functions as a small library. For example, you will probably have to implement the `wb_differential_wheels_set_speed()` function to send a specific command to the real robot with the wheel speeds as an argument. This command can be sent to the real robot via the serial port of the PC, or any other PC-robot interface you have. You will probably need to make some unit conversions, since your robot may not use the same units of measurement as the ones used in Webots. The same applies for reading sensor values from the real robot.

Developing a remote control plugin

Webots already provides some facilities to implement a remote control library and in particular it is possible to develop it as a controller plugin. Once set in the corresponding field of the Robot node, this remote control plugin will be executed automatically when running the controller. Implementation details are described in subsection 6.6.5.

Special functions

The `wb_robot_init()` function must be the first called function. It performs the controller library's initialization.

The `wb_robot_step()` function should be called repeatedly (typically in an infinite loop). It requests that the simulator performs a simulation step of ms milliseconds; that is, to advance the simulation by this amount of time.

The `wb_robot_cleanup()` function should be called at the end of a program in order to leave the controller cleanly.

Running your real robot

Once linked with your own remote control plugin, you can control your real robot by running the simulation in Webots. It might be useful to also add a robot window plugin (see subsection 6.6.2) to graphically display specific sensor values, motor commands or a stop button.

Such a remote control system is designed to be implemented in C/C++ as explained in section 6.6; however, it can also be implemented other programming languages creating a wrapper.

5.8.2 Cross-compilation

Overview

Developing a cross-compilation system will allow you to recompile your Webots controller for the embedded processor of your own real robot. Hence, the source code you wrote for the Webots simulation will be executed on the real robot itself, and there is no need to have a permanent PC connection with the robot as with the remote control system. This is only possible if the processor on your robot can be programmed respectively in C, C++, Java or Python. It is not possible for a processor that can be programmed only in assembler or another specific language. Webots includes the source code of such a cross-compilation system for the e-puck and the Hemisson robot. Samples are located in the `WEBOTS_MODULES_PATH/projects/robots` directory.

Developing a custom library

Unlike the remote control system, the cross-compilation system requires that the source code of your Webots controller be recompiled using the cross-compilation tools specific to your own robot. You will also need to rewrite the Webots include files to be specific to your own robot. In simple cases, you can just rewrite the Webots include files you need, as in the `hemisson` example. In more complex cases, you will also need to write some C source files to be used as a replacement for the Webots `Controller` library, but running on the real robot. You should then recompile your Webots controller with your robot cross-compilation system and link it with your robot library. The resulting file should be uploaded onto the real robot for local execution.

Examples

Webots support cross-compilation for several existing commercial robots. For the e-puck™robot, this system is fully integrated in Webots and needs no modification in the code. For the Hemisson™robot, this system needs a few include files to replace the Webots API include files. For the Khepera™robot, a specific C library is used in addition to specific include files.

5.8.3 Interpreted language

In some cases, it may be better to implement an interpreted language system. This is useful if your real robot already uses an interpreted language, like Basic or a graph based control language. In this case, the transfer is very easy since you can directly transfer the code of your program that will be interpreted to the real robot. The most difficult part may be to develop a language interpreter in C or Java to be used by your Webots controller for controlling the simulated robot. Such an interpreted language system was developed for the Hemisson™robot with the BotStudio™system.

Chapter 6

Programming Fundamentals

This chapter introduces the basic concepts of programming with Webots. Webots controllers can be written in C/C++, Java, Python or MATLAB™. Besides their syntactic differences all these languages share the same low-level implementation. As long as the sequence of function/method calls does not vary, every programming language will yield exactly the same simulation results. Hence the concepts explained here with C examples also apply to C++/Java/Python/Matlab.

6.1 Controller Programming

The programming examples provided here are in C, but same concepts apply to C++/Java/Python/Matlab.

6.1.1 Hello World Example

The tradition in computer science is to start with a "Hello World!" example. So here is a "Hello World!" example for a Webots controller:

```
1  #include <webots/robot.h>
2  #include <stdio.h>
3
4  int main() {
5    wb_robot_init();
6
7    while (1) {
8      printf("Hello World!\n");
9      wb_robot_step(32);
10   }
11
12   return 0;
13 }
```

This code repeatedly prints `"Hello World!"` to the standard output stream which is redirected to Webots console. The standard output and error streams are automatically redirected to Webots console for all Webots supported languages.

Webots C API (Application Programming Interface) is provided by regular C header files. These header files must be included using statements like `#include <webots/xyz.h>` where `xyz` represents the name of a Webots node in lowercase. Like with any regular C code it is also possible to include the standard C headers, e.g. `#include <stdio.h>`. A call to the initialization function `wb_robot_init()` is required before any other C API function call. This function initializes the communication between the controller and Webots. Note that `wb_robot_init()` exists only in the C API, it does not have any equivalent in the other supported programming languages.

Usually the highest level control code is placed inside a `for` or a `while` loop. Within that loop there is a call to the `wb_robot_step()` function. This function synchronizes the controller's data with the simulator. The function `wb_robot_step()` needs to be present in every controller and it must be called at regular intervals, therefore it is usually placed in the main loop as in the above example. The value 32 specifies the duration of the control steps, i.e. the function `wb_robot_step()` shall compute 32 milliseconds of simulation and then return. This duration specifies an amount of simulated time, not real (wall clock) time, so it may actually take 1 millisecond or one minute of CPU time, depending on the complexity of the simulated world.

Note that in this "Hello World!" example the `while` loop has no exit condition, hence the return statement is never reached. It is usual to have an infinite loop like this in the controller code: the result is that the controller runs as long as the simulation runs.

6.1.2 Reading Sensors

Now that we have seen how to print a message to the console, we shall see how to read the sensors of a robot. The next example does continuously update and print the value returned by a `DistanceSensor`:

```
1  #include <webots/robot.h>
2  #include <webots/distance_sensor.h>
3  #include <stdio.h>
4
5  #define TIME_STEP 32
6
7  int main() {
8    wb_robot_init();
9
10   WbDeviceTag ds = wb_robot_get_device("my_distance_sensor");
11   wb_distance_sensor_enable(ds, TIME_STEP);
12
13   while (1) {
```

```
14      wb_robot_step(TIME_STEP);
15      double dist = wb_distance_sensor_get_value(ds);
16      printf("sensor value is %f\n", dist);
17    }
18
19    return 0;
20  }
```

As you can notice, prior to using a device, it is necessary to get the corresponding device tag (`WbDeviceTag`); this is done using the `wb_robot_get_device()` function. The `WbDeviceTag` is an opaque type that is used to identify a device in the controller code. Note that the string passed to this function, *"my_distance_sensor"* in this example, refers to a device name specified in the robot description (`.wbt` or `.proto` file). If the robot has no device with the specified name, this function returns 0.

Each sensor must be enabled before it can be used. If a sensor is not enabled it returns undefined values. Enabling a sensor is achieved using the corresponding `wb_*_enable()` function, where the star (*) stands for the sensor type. Every `wb_*_enable()` function allows to specify an update delay in milliseconds. The update delay specifies the desired interval between two updates of the sensor's data.

In the usual case, the update delay is chosen to be similar to the control step (`TIME_STEP`) and hence the sensor will be updated at every `wb_robot_step()`. If, for example, the update delay is chosen to be twice the control step then the sensor data will be updated every two `wb_robot_step()`: this can be used to simulate a slow device. Note that a larger update delay can also speed up the simulation, especially for CPU intensive devices like the `Camera`. On the contrary, it would be pointless to choose an update delay smaller than the control step, because it will not be possible for the controller to process the device's data at a higher frequency than that imposed by the control step. It is possible to disable a device at any time using the corresponding `wb_*_disable()` function. This may increase the simulation speed.

The sensor value is updated during the call to `wb_robot_step()`. The call to `wb_distance_sensor_get_value()` retrieves the latest value.

Note that some device return vector values instead of scalar values, for example these functions:

```
1  const double *wb_gps_get_values(WbDeviceTag tag);
2  const double *wb_accelerometer_get_values(WbDeviceTag tag);
3  const double *wb_gyro_get_values(WbDeviceTag tag);
```

Each function returns a pointer to three double values. The pointer is the address of an array allocated by the function internally. These arrays should never be explicitly deleted by the controller code. They will be automatically deleted when necessary. The array contains exactly three double values. Hence accessing the array beyond index 2 is illegal and may crash the controller. Finally, note that the array elements should not be modified, for this reason the pointer is declared as *const*. Here are correct examples of code using these functions:

```
const double *pos = wb_gps_get_values(gps);

// OK, to read the values they should never be explicitly
   deleted by the controller code.
printf("MY_ROBOT is at position: %g %g %g\n", pos[0], pos[1],
   pos[2]);

// OK, to copy the values
double x, y, z;
x = pos[0];
y = pos[1];
z = pos[2];

// OK, another way to copy the values
double a[3] = { pos[0], pos[1], pos[2] };

// OK, yet another way to copy these values
double b[3];
memcpy(b, pos, sizeof(b));
```

And here are incorrect examples:

```
const double *pos = wb_gps_get_values(gps);

pos[0] = 3.5;       // ERROR: assignment of read-only location
double a = pos[3]; // ERROR: index out of range
delete [] pos;      // ERROR: illegal free
free(pos);          // ERROR: illegal free
```

6.1.3 Using Actuators

The example below shows how to make a rotational motor oscillate with a 2 Hz sine signal.

Just like sensors, each Webots actuator must be identified by a `WbDeviceTag` returned by the `wb_robot_get_device()` function. However, unlike sensors, actuators don't need to be expressly enabled; they actually don't have `wb_*_enable()` functions.

To control a motion, it is generally useful to decompose that motion in discrete steps that correspond to the control step. As before, an infinite loop is used here: at each iteration a new target position is computed according to a sine equation. The `wb_motor_set_position()` function stores a new position request for the corresponding rotational motor. Note that `wb_motor_set_position()` stores the new position, but it does not immediately actuate the motor. The effective actuation starts on the next line, in the call to `wb_robot_step()`. The `wb_robot_step()` function sends the actuation command to the `RotationalMotor` but

it does not wait for the RotationalMotor to complete the motion (i.e. reach the specified target position); it just simulates the motor's motion for the specified number of milliseconds.

```
#include <webots/robot.h>
#include <webots/motor.h>
#include <math.h>

#define TIME_STEP 32

int main() {
  wb_robot_init();

  WbDeviceTag motor = wb_robot_get_device("my_motor");

  double F = 2.0;   // frequency 2 Hz
  double t = 0.0;   // elapsed simulation time

  while (1) {
    double pos = sin(t * 2.0 * M_PI * F);
    wb_motor_set_position(motor, pos);
    wb_robot_step(TIME_STEP);
    t += (double)TIME_STEP / 1000.0;
  }

  return 0;
}
```

When wb_robot_step() returns, the motor has moved by a certain (linear or rotational) amount which depends on the target position, the duration of the control step (specified with wb_robot_step()), the velocity, acceleration, force, and other parameters specified in the .wbt description of the Motor. For example, if a very small control step or a low motor velocity is specified, the motor will not have moved much when wb_robot_step() returns. In this case several control steps are required for the RotationalMotor to reach the target position. If a longer duration or a higher velocity is specified, then the motor may have fully completed the motion when wb_robot_step() returns.

Note that wb_motor_set_position() only specifies the *desired* target position. Just like with real robots, it is possible (in physics-based simulations only), that the RotationalMotro is not able to reach this position, because it is blocked by obstacles or because the motor's torque (maxForce) is insufficient to oppose to the gravity, etc.

If you want to control the motion of several RotationalMotors simultaneously, then you need to specify the desired position for each RotationalMotor separately, using wb_motor_set_position(). Then you need to call wb_robot_step() once to actuate all the RotationalMotors simultaneously.

6.1.4 How to use wb_robot_step()

Webots uses two different time steps:

- The control step (the argument of the `wb_robot_step()` function)
- The simulation step (specified in the Scene Tree: `WorldInfo.basicTimeStep`)

The control step is the duration of an iteration of the control loop. It corresponds to the parameter passed to the `wb_robot_step()` function. The `wb_robot_step()` function advances the controller time of the specified duration. It also synchronizes the sensor and actuator data with the simulator according to the controller time.

Every controller needs to call `wb_robot_step()` at regular intervals. If a controller does not call `wb_robot_step()` the sensors and actuators won't be updated and the simulator will block (in synchronous mode only). Because it needs to be called regularly, `wb_robot_step()` is usually placed in the main loop of the controller.

The simulation step is the value specified in `WorldInfo.basicTimeStep` (in milliseconds). It indicates the duration of one step of simulation, i.e. the time interval between two computations of the position, speed, collisions, etc. of every simulated object. If the simulation uses physics (vs. kinematics), then the simulation step also specifies the interval between two computations of the forces and torques that need to be applied to the simulated rigid bodies.

The execution of a simulation step is an atomic operation: it cannot be interrupted. Hence a sensor measurement or a motor actuation can only take place between two simulation steps. For that reason the control step specified with each `wb_robot_step()` must be a multiple of the simulation step. So for example, if the simulation step is 16 ms, then the control step argument passed to `wb_robot_step()` can be 16, 32, 64, 128, etc.

6.1.5 Using Sensors and Actuators Together

Webots and each robot controller are executed in separate processes. For example, if a simulation involves two robots, there will be three processes in total: one for Webots and two for the two robots. Each controller process exchanges sensors and actuators data with the Webots process during the calls to `wb_robot_step()`. So for example, `wb_motor_set_position()` does not immediately send the data to Webots. Instead it stores the data locally and the data are effectively sent when `wb_robot_step()` is called.

For that reason the following code snippet is a bad example. Clearly, the value specified with the first call to `wb_motor_set_position()` will be overwritten by the second call:

```
1 wb_motor_set_position(my_leg, 0.34);  // BAD: ignored
2 wb_motor_set_position(my_leg, 0.56);
3 wb_robot_step(40);
```

Similarly this code does not make much sense either:

```
while (1) {
  double d1 = wb_distance_sensor_get_value(ds1);
  double d2 = wb_distance_sensor_get_value(ds1);
  if (d2 < d1)   // WRONG: d2 will always equal d1 here
    avoidCollision();
  wb_robot_step(40);
}
```

since there was no call to `wb_robot_step()` between the two sensor readings, the values returned by the sensor cannot have changed in the meantime. A working version would look like this:

```
while (1) {
  double d1 = wb_distance_sensor_get_value(ds1);
  wb_robot_step(40);
  double d2 = wb_distance_sensor_get_value(ds1);
  if (d2 < d1)
    avoidCollision();
  wb_robot_step(40);
}
```

However the generally recommended approach is to have a single `wb_robot_step()` call in the main control loop, and to use it to update all the sensors and actuators simultaneously, like this:

```
while (1) {
  readSensors();
  actuateMotors();
  wb_robot_step(TIME_STEP);
}
```

Note that it may also be judicious to move `wb_robot_step()` to the beginning of the loop, in order to make sure that the sensors already have valid values prior to entering the `readSensors()` function. Otherwise the sensors will have undefined values during the first iteration of the loop, hence:

```
while (1) {
  wb_robot_step(TIME_STEP);
  readSensors();
  actuateMotors();
}
```

Here is a complete example of using sensors and actuators together. The robot used here is a `DifferentialWheels` using differential steering. It uses two proximity sensors (`DistanceSensor`) to detect obstacles.

```c
#include <webots/robot.h>
#include <webots/differential_wheels.h>
#include <webots/distance_sensor.h>

#define TIME_STEP 32

int main() {
  wb_robot_init();

  WbDeviceTag left_sensor = wb_robot_get_device("left_sensor");
  WbDeviceTag right_sensor = wb_robot_get_device("right_sensor");
  wb_distance_sensor_enable(left_sensor, TIME_STEP);
  wb_distance_sensor_enable(right_sensor, TIME_STEP);

  while (1) {
    wb_robot_step(TIME_STEP);

    // read sensors
    double left_dist = wb_distance_sensor_get_value(left_sensor);
    double right_dist = wb_distance_sensor_get_value(right_sensor);

    // compute behavior
    double left = compute_left_speed(left_dist, right_dist);
    double right = compute_right_speed(left_dist, right_dist);

    // actuate wheel motors
    wb_differential_wheels_set_speed(left, right);
  }

  return 0;
}
```

6.1.6 Using Controller Arguments

In the `.wbt` file, it is possible to specify arguments that are passed to a controller when it starts. They are specified in the `controllerArgs` field of the `Robot`, `Supervisor` or `DifferentialWheels` node, and they are passed as parameters of the `main()` function. For example, this can be used to specify parameters that vary for each robot's controller.

For example if we have:

```
Robot {
  ...
  controllerArgs "one two three"
  ...
}
```

and if the controller name is *"demo"*, then this sample controller code:

```
1  #include <webots/robot.h>
2  #include <stdio.h>
3
4  int main(int argc, const char *argv[]) {
5    wb_robot_init();
6
7    int i;
8    for (i = 0; i < argc; i++)
9      printf("argv[%i]=%s\n", i, argv[i]);
10
11   return 0;
12 }
```

will print:

```
argv[0]=demo
argv[1]=one
argv[2]=two
argv[3]=three
```

6.1.7 Controller Termination

Usually a controller process runs in an endless loop: it is terminated (killed) by Webots when the user reverts (reloads) the simulation or quits Webots. The controller cannot prevent its own termination but it can be notified shortly before this happens. The `wb_robot_step()` function returns -1 when the process is going to be terminated by Webots. Then the controller has 1 second (clock time) to save important data, close files, etc. before it is effectively killed by Webots. Here is an example that shows how to detect the upcoming termination:

```
1  #include <webots/robot.h>
2  #include <webots/distance_sensor.h>
3  #include <stdio.h>
4
5  #define TIME_STEP 32
6
7  int main() {
8    wb_robot_init();
9
```

```
  WbDeviceTag ds = wb_robot_get_device("my_distance_sensor");
  wb_distance_sensor_enable(ds, TIME_STEP);

  while (wb_robot_step(TIME_STEP) != -1) {
    double dist = wb_distance_sensor_get_value();
    printf("sensor value is %f\n", dist);
  }

  // Webots triggered termination detected!

  saveExperimentData();

  wb_robot_cleanup();

  return 0;
}
```

In some cases, it is up to the controller to make the decision of terminating the simulation. For example in the case of search and optimization algorithms: the search may terminate when a solution is found or after a fixed number of iterations (or generations).

In this case the controller should just save the experiment results and quit by returning from the `main()` function or by calling the `exit()` function. This will terminate the controller process and freeze the simulation at the current simulation step. The physics simulation and every robot involved in the simulation will stop.

```
// freeze the whole simulation
if (finished) {
  saveExperimentData();
  exit(0);
}
```

If only one robot controller needs to terminate but the simulation should continue with the other robots, then the terminating robot should call `wb_robot_cleanup()` right before quitting:

```
// terminate only this robot controller
if (finished) {
  saveExperimentsData();
  wb_robot_cleanup();
  exit(0);
}
```

Note that the exit status as well as the value returned by the `main()` function are ignored by Webots.

6.1.8 Shared libraries

Creating shared libraries can be very useful to share code between controllers and/or plugins. There are several ways to do so, but we recommend to place them into a subdirectory of the `libraries` directory of your project. Indeed the environment variables of the controllers are modified to include these paths into your [[DY]LD_LIBRARY_]PATH environment variable (depending on the OS). Moreover the main Makefile (`WEBOTS_HOME/resources/Makefile.include`) used to compile Webots controllers is able to create shared libraries and to link easily with the Controller libraries, ODE or the Qt framework.

A good example of this is the Qt utility library located there: `WEBOTS_HOME/resources/projects/libraries/qt_utils`

If for some reason shared libraries cannot be in the `libraries` directory, the `WEBOTS_LIBRARY_PATH` environment variable will be very helpful. The paths it contains will be added at the beginning of the library search path([[DY]LD_LIBRARY_]PATH) when starting the controller.

6.1.9 Environment variables

For some projects it will be necessary to define or change variables defined in your environment. They can be changed in the settings of the computer but it may last only for the current session or create conflict with other applications or projects. Webots offers an elegant solution to this. A configuration file named `runtime.ini` can be added to the controller directory. Any environment variable defined in this file will be loaded to the environment each time the controller starts.

This configuration file uses the standard INI template that is really simple and easy to write and read. It contains pairs of key and value that can be inside [sections]. Comments can be written on a line after using a semicolon ';' character.

Environment variables in this file can contain references to other environment variables using this syntax : `$(MY_VARIABLE_NAME)`. They will be automatically replaced by the actual value already existing in the environment. The Webots `runtime.ini` supports 7 sections:

- `[environment variables with relative paths]`

  This section should contain only environment variables with relative paths. Paths must be separated by the colon symbol ':' and the separator between directories is the slash symbol '/'. Variables declared in this section will be add on every platform. On Windows, colons will be replaced by semicolon and slash will be replaced by backslash according to the Windows syntax.

- `[environment variables]`

Environment variables defined in this section will also be added to the environment on every platform but they will be written directly with no syntax change. It's a good place for variables that don't contain any path.

- `[environment variables for Windows]`

  Variables defined in this section will only be added to the environment if the controller is run on the Windows platform. If you want to declare paths in this section, the value should be written between double-quotes symbols ".

- `[environment variables for Mac OS X]`

  Variables defined here will only be added on Mac OS X and ignored on other platforms.

- `[environment variables for Linux]`

  Variables defined here will be added on all Linux platforms but not on Mac or Windows.

- `[environment variables for Linux 32]`

  These variables will be added only if the Linux platform is 32 bit.

- `[environment variables for Linux 64]`

  These variables will be added only if the Linux platform is 64 bit.

Here is an example of a typical runtime.ini file.

```
1  ; typical runtime.ini
2
3  [environment variables with relative paths]
4  WEBOTS_LIBRARY_PATH = lib:$(WEBOTS_LIBRARY_PATH):../../
       library
5
6  [environment variables]
7  ROS_MASTER_URI = http://localhost:11311
8
9  [environment variables for Windows]
10 NAOQI_LIBRARY_FOLDER = "bin;C:\Users\My Documents\Naoqi\
       bin"
11
12 [environment variables for Mac OS X]
13 NAOQI_LIBRARY_FOLDER = lib
14
15 [environment variables for Linux]
16 NAOQI_LIBRARY_FOLDER = lib
```

6.1.10 Languages settings

The `runtime.ini` file may also contain language specific sections, named `[java]`, `[python]` and `[matlab]`. Each of this section may include two keys, namely `COMMAND` and `OPTIONS`. The `COMMAND` key allows you to define a specific version of the language interpreter whereas the `OPTIONS` key allows you to specific options that will be passed immediately to the language interpreter. For example:

```
; runtime.ini for a Python controller on Mac OS X

[python]
COMMAND = /opt/local/bin/python2.7
OPTIONS = -m package.name.given
```

In the above example, the resulting command issued by Webots will be: `/opt/local/bin/python2.7 -m package.name.given my_controller.py` possibly followed by the value of the `controllerArgs` field of the corresponding `Robot` node.

```
; runtime.ini for a Java controller on Windows

[environment variables with relative paths]
CLASSPATH = ../lib/MyLibrary.jar

[java]
COMMAND = javaw.exe
OPTIONS = -Xms6144k
```

The Java `-classpath` (or `-cp`) option is automatically generated from the `CLASSPATH` environment variable. Therefore you should not add it to the `OPTIONS` key, but rather to a standard environment variable in your `runtime.ini` file. In the above example, the final `-classpath` option passed to the Java virtual machine includes `$(WEBOTS_HOME)/lib/Controller.jar`, either the current directory (`.`) or, if present, the controller jar file (`MyController.jar`) and finally `../lib/MyLibrary.jar`.

6.2 Supervisor Programming

The programming examples provided here are in C, but same concepts apply to C++/Java/Python/Matlab.

6.2.1 Introduction

The `Supervisor` is a special kind of `Robot`. In object-oriented jargon we would say that the `Supervisor` class *inherits* from the `Robot` class or that the `Supervisor` class *extends* the `Robot` class. The important point is that the `Supervisor` node offers the `wb_supervisor_*()` functions in addition to the regular `wb_robot_*()` functions. These extra functions can only be invoked from a controller program associated with a `Supervisor` node, not with a `Robot` or a `DifferentialWheels` node. Note that Webots PRO is required to create `Supervisor` nodes or use the `wb_supervisor_*()` functions.

In the Scene Tree, a `Supervisor` node can be used in the same context where a `Robot` node is used, hence it can be used as a basis node to model a robot. But in addition, the `wb_supervisor_*()` functions can also be used to control the simulation process and modify the Scene Tree. For example the `Supervisor` can replace human actions such as measuring the distance travelled by a robot or moving it back to its initial position, etc. The `Supervisor` can also take a screen shot or a video of the simulation, restart or terminate the simulation, etc. It can read or modify the value of every fields in the Scene Tree, e.g. read or change the position of robots, the color of objects, or switch on or off the light sources, and do many other useful things.

One important thing to keep in mind is that the `Supervisor` functions correspond to functionalities that are usually not available on real robots; they rather correspond to a human intervention on the experimental setup. Hence, the `Robot` vs. `Supervisor` distinction is intentional and aims at reminding the user that `Supervisor` code may not be easily transposed to real robots.

Now let's examine a few examples of `Supervisor` code.

6.2.2 Tracking the Position of Robots

The `Supervisor` is frequently used to record robots trajectories. Of course, a robot can find its position using a GPS, but when it is necessary to keep track of several robots simultaneously and in a centralized way, it is much simpler to use a `Supervisor`.

The following `Supervisor` code shows how to keep track of a single robot, but this can easily be transposed to an arbitrary number of robots. This example code finds a `WbNodeRef` that corresponds to the robot node and then a `WbFieldRef` that corresponds to the robot's `translation` field. At each iteration it reads and prints the field's values.

```
1 #include <webots/robot.h>
2 #include <webots/supervisor.h>
3 #include <stdio.h>
4
5 int main() {
6   wb_robot_init();
7
8   // do this once only
```

```
 9   WbNodeRef robot_node = wb_supervisor_node_get_from_def("
       MY_ROBOT");
10   WbFieldRef trans_field = wb_supervisor_node_get_field(
       robot_node, "translation");
11
12   while (1) {
13     // this is done repeatedly
14     const double *trans = wb_supervisor_field_get_sf_vec3f(
         trans_field);
15     printf("MY_ROBOT is at position: %g %g %g\n", trans[0],
         trans[1], trans[2]);
16     wb_robot_step(32);
17   }
18
19   return 0;
20 }
```

Note that a `Supervisor` controller must include the `supervisor.h` header file in addition to the `robot.h` header file. Otherwise the `Supervisor` works like a regular `Robot` controller and everything that was explained in the "Controller Programming" section does also apply to "Supervisor Programming".

As illustrated by the example, it is better to get the `WbNodeRefs` and `WbFieldRefs` only once, at the beginning of the simulation (keeping the invariants out of the loop). The call to `wb_supervisor_node_get_from_def()` searches for an object named "MY_ROBOT" in the Scene Tree. Note that the name in question is the DEF name of the object, not the name field which is used to identify devices. The function returns a `WbNodeRef` which is an opaque and unique reference to the corresponding Scene Tree node. Then the call to `wb_supervisor_node_get_field()` finds a `WbFieldRef` in the specified node. The "translation" field represents the robot's position in the global (world) coordinate system.

In the `while` loop, the call to `wb_supervisor_field_get_sf_vec3f()` is used to read the latest values of the specified field. Note that, unlike sensor or actuator functions, the `wb_supervisor_field_*()` functions are executed immediately: their execution is not postponed to the next `wb_robot_step()` call.

6.2.3 Setting the Position of Robots

Now let's examine a more sophisticated `Supervisor` example. In this example we seek to optimize the locomotion of a robot: it should walk as far as possible. Suppose that the robot's locomotion depends on two parameters (a and b), hence we have a two-dimensional search space.

In the code, the evaluation of the a and b parameters is carried out in the the `while` loop. The `actuateMotors()` function here is assumed to call `wb_motor_set_postion()` for each motor involved in the locomotion. After each evaluation the distance travelled by the robot is

measured and logged. Then the robot is moved (translation) back to its initial position (0, 0.5, 0) for the next evaluation. To move the robot we need the `wb_supervisor_*()` functions and hence the base node of this robot in the Scene Tree must be a `Supervisor` and not a Robot.

```
#include <webots/robot.h>
#include <webots/supervisor.h>
#include <stdio.h>
#include <math.h>

#define TIME_STEP 32

int main() {
  wb_robot_init();

  // get handle to robot's translation field
  WbNodeRef robot_node = wb_supervisor_node_get_from_def("
     MY_ROBOT");
  WbFieldRef trans_field = wb_supervisor_node_get_field(
     robot_node, "translation");

  double a, b, t;
  for (a = 0.0; a < 5.0; a += 0.2) {
    for (b = 0.0; b < 10.0; b += 0.3) {
      // evaluate robot during 60 seconds (simulation time)
      for (t = 0.0; t < 60.0; t += TIME_STEP / 1000.0) {
        actuateMotors(a, b, t);
        wb_robot_step(TIME_STEP);
      }

      // compute travelled distance
      const double *pos = wb_supervisor_field_get_sf_vec3f(
         trans_field);
      double dist = sqrt(pos[0] * pos[0] + pos[2] * pos[2]);
      printf("a=%g, b=%g -> dist=%g\n", a, b, dist);

      // reset robot position
      const double INITIAL[3] = { 0, 0.5, 0 };
      wb_supervisor_field_set_sf_vec3f(trans_field, INITIAL);
    }
  }

  return 0;
}
```

As in the previous example, the `trans_field` variable is a `WbFieldRef` that identifies the `translation` field of the robot. In this example the `trans_field` is used both for getting

(`wb_supervisor_field_get_sf_vec3f()`) and for setting (`wb_supervisor_field_set_sf_vec3f`) the field's value.

Please note that the program structure is composed of three nested `for` loops. The two outer loops change the values of the a and b parameters. The innermost loop makes the robot walk during 60 seconds. One important point here is that the call to `wb_robot_step()` is placed in the innermost loop. This allows the motor positions to be updated at each iteration of the loop. If `wb_robot_step()` was placed anywhere else, this would not work.

6.3 Using Numerical Optimization Methods

6.3.1 Choosing the correct Supervisor approach

There are several approaches to using optimization algorithms in Webots. Most approaches need a `Supervisor` and hence Webots PRO is usually required.

A numerical optimization can usually be decomposed in two separate tasks:

1. Running the optimization algorithm: Systematical Search, Random Search, Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Simulated Annealing, etc.
2. Running the robot behavior with a set of parameters specified by the optimization algorithm.

One of the important things that needs to be decided is whether the implementation of these two distinct tasks should go into the same controller or in two separate controllers. Let's discuss both approaches:

Using a single controller

If your simulation needs to evaluate only one robot at a time, e.g. you are optimizing the locomotion gait of a humanoid or the behavior of a single robot, then it is possible to have both tasks implemented in the same controller; this results in a somewhat simpler code. Here is a pseudo-code example for the systematical optimization of two parameters a and b using only one controller:

```
1 #include <webots/robot.h>
2 #include <webots/supervisor.h>
3
4 #define TIME_STEP 5
5
6 int main() {
7   wb_robot_init();
```

```
  double a, b, time;
  for (a = 0.5; a < 10.0; a += 0.1) {
    for (b = 0.1; b < 5.0; b += 0.5) {
      resetRobot();  // move robot to initial position

      // run robot simulation for 30 seconds
      for (time = 0.0; time < 30.0; time += TIME_STEP / 1000.0)
          {
        actuateMotors(a, b, time);
        wb_robot_step(TIME_STEP);
      }

      // compute and print fitness
      double fitness = computeFitness();
      printf("with parameters: %g %g, fitness was: %g\n", a, b,
          fitness);
    }
  }

  wb_robot_cleanup();
  return 0;
}
```

In this example the robot runs for 30 simulated seconds and then the fitness is evaluated and the robot is moved back to it initial position. Note that this controller needs to be executed in a `Supervisor` in order to access the `wb_supervisor_field_*()` functions that are necessary to read and reset the robot's position. So when using this approach, the robot must be based on a `Supervisor` node in the Scene Tree. Note that this approach is not suitable to optimize a `DifferentialWheels` robot, because due to the class hierarchy, a robot cannot be a `DifferentialWheels` and a `Supervisor` at the same time.

Using two distinct types of controllers

If, on the contrary, your simulation requires the simultaneous execution of several robots, e.g. swarm robotics, or if your robot is a `DifferentialWheels`, then it is advised to use two distinct types of controller: one for the optimization algorithm and one for the robot's behavior. The optimization algorithm should go in a `Supervisor` controller while the robots' behavior can go in a regular (non-Supervisor) controller.

Because these controllers will run in separate system processes, they will not be able to access each other's variables. Though, they will have to communicate by some other means in order to specify the sets of parameters that need to be evaluated. It is possible, and recommended, to use Webots `Emitters` and `Receivers` to exchange information between the `Supervisor` and the other controllers. For example, in a typical scenario, the `Supervisor` will send evaluation

parameters (e.g., genotype) to the robot controllers. The robot controllers listen to their `Receivers`, waiting for a new set of parameters. Upon receipt, a robot controller starts executing the behavior specified by the set of parameters. In this scenario, the `Supervisor` needs an `Emitter` and each individual robot needs a `Receiver`.

Depending on the algorithms needs, the fitness could be evaluated either in the `Supervisor` or in the individual robot controllers. In the case it is evaluated in the robot controller then the fitness result needs to be sent back to the `Supervisor`. This bidirectional type of communication requires the usage of additional `Emitters` and `Receivers`.

6.3.2 Resetting the robot

When using optimization algorithm, you will probably need to reset the robot after or before each fitness evaluation. There are several approaches to resetting the robot:

Using the wb_supervisor_field_set_*() and wb_supervisor_simulation_reset_physics() functions

You can easily reset the position, orientation and physics of the robot using the `wb_supervisor_field_set...()` and `wb_supervisor_simulation_reset_physics()` functions, here is an example:

```
1  // get handles to the robot's translation and rotation fields
2  WbNodeRef robot_node = wb_supervisor_node_get_from_def("
       MY_ROBOT");
3  WbFieldRef trans_field = wb_supervisor_node_get_field(
       robot_node, "translation");
4  WbFieldRef rot_field = wb_supervisor_node_get_field(robot_node,
        "rotation");
5
6  // reset the robot
7  const double INITIAL_TRANS[3] = { 0, 0.5, 0 };
8  const double INITIAL_ROT[4] = { 0, 1, 0, 1.5708 };
9  wb_supervisor_field_set_sf_vec3f(trans_field, INITIAL_TRANS);
10 wb_supervisor_field_set_sf_rotation(rot_field, INITIAL_ROT);
11 wb_supervisor_simulation_reset_physics();
```

The drawback with the above method is that it only resets the robot's main position and orientation. This may be fine for some types of optimization, but insufficient for others. Although it is possible to add more parameters to the set of data to be reset, it is sometimes difficult to reset everything. Neither motor positions, nor the robot controller(s) are reset this way. The motor positions should be reset using the `wb_motor_set_position()` and the robot controller should be reset by sending a message from the supervisor process to the robot controller process (using

Webots `Emitter` / `Receiver` communication system). The robot controller program should be able to handle such a message and reset its state accordingly.

Using the wb_supervisor_simulation_revert() function

This function restarts the physics simulation and all controllers from the very beginning. With this method, everything is reset, including the physics and the motor positions and the controllers. But this function does also restart the controller that called `wb_supervisor_simulation_revert()`, this is usually the controller that runs the optimization algorithm, and as a consequence the optimization state is lost. Hence for using this technique, it is necessary to develop functions that can save and restore the complete state of the optimization algorithm. The optimization state should be saved before calling `wb_supervisor_simulation_revert()` and reloaded when the `Supervisor` controller restarts. Here is a pseudo-code example:

```
#include <webots/robot.h>
#include <webots/supervisor.h>

void run_robot(const double params[]) {
  read_sensors(params);
  compute_behavior(params):
  actuate_motors(params);
}

void evaluate_next_robot() {
  const double *params = optimizer_get_next_parameters();
  ...
  // run robot for 30 seconds
  double time;
  for (time = 0.0; time < 30.0; time += TIME_STEP / 1000.0) {
    run_robot(params);
    wb_robot_step(TIME_STEP);
  }
  ...
  // compute and store fitness
  double fitness = compute_fitness();
  optimizer_set_fitness(fitness);
  ...
  // save complete optimization state to a file
  optimizer_save_state("my_state_file.txt");
  ...
  // start next evaluation
  wb_supervisor_simulation_revert();
  wb_robot_step(TIME_STEP);
  exit(0);
}
```

```
32
33 int main() {
34   wb_robot_init();
35   ...
36   // reload complete optimization state
37   optimizer_load_state("my_state_file.txt");
38   ...
39   if (optimizer_has_more_parameters())
40     evaluate_next_robot();
41   ...
42   wb_robot_cleanup();
43   return 0;
44 }
```

If this technique is used with Genetic Algorithms for example, then the function `optimizer_save_state()` should save at least all the genotypes and fitness results of the current GA population. If this technique is used with Particle Swarm Optimization, then the `optimizer_save_state()` function should at least save the position, velocity and fitness of all particles currently in the swarm.

By starting and quitting Webots

Finally, the last method is to start and quit the Webots program for each parameter evaluation. This may sound like an overhead, but in fact Webots startup time is usually very short compared to the time necessary to evaluate a controller, so this approach makes perfectly sense.

For example, Webots can be called from a shell script or from any type of program suitable for running the optimization algorithm. Starting Webots each time does clearly revert the simulation completely, so each robot will start from the same initial state. The drawback of this method is that the optimization algorithm has to be programmed outside of Webots. This external program can be written in any programming language, e.g. shell script, C, PHP, perl, etc., provided that there is a way to call webots and wait for its termination, e.g. like the C standard `system()` does. On the contrary, the parameter evaluation must be implemented in a Webots controller.

With this approach, the optimization algorithm and the robot controller(s) run in separate system processes, but they must communicate with each other in order to exchange parameter sets and fitness results. One simple way is to make them communicate by using text files. For example, the optimization algorithm can write the genotypes values into a text file then call Webots. When Webots starts, the robot controller reads the genotype file and carries out the parameter evaluation. When the robot controller finishes the evaluation, it writes the fitness result into another text file and then it calls the `wb_supervisor_simulation_quit()` function to terminate Webots. Then the control flow returns to the optimization program that can read the resulting fitness, associate it with the current genotype and proceed with the next genotype.

Here is a possible (pseudo-code) implementation for the robot evaluation controller:

```c
#include <webots/robot.h>
#include <webots/supervisor.h>

#define TIME_STEP 10

double genotype[GENOME_SIZE];

int main() {
  wb_robot_init();
  ...
  genotype_read("genotype.txt", genotype);
  ...
  // run evaluation for 30 seconds
  for (double time = 0.0; time < 30.0; time += TIME_STEP /
     1000.0) {
    read_sensors(genotype);
    actuate_motors(time, genotype);
    wb_robot_step(TIME_STEP);
  }
  ...
  double fitness = compute_fitness();
  fitness_save(fitness, "fitness.txt");
  ...
  wb_supervisor_simulation_quit();
  wb_robot_step(TIME_STEP);
  return 0;
}
```

You will find complete examples of simulations using optimization techniques in Webots distribution: look for the worlds called `advanced_particle_swarm_optimization.wbt` and `advanced_genetic_algorithm.wbt` located in the `WEBOTS_MODULES_PATH/projects/samples/curriculum/worlds` directory. These examples are described in the *Advanced Programming Exercises* of Cyberbotics' Robot Curriculum[1].

6.4 C++/Java/Python

This section explains the main differences between the C API and the C++/Java/Python APIs.

[1] `http://en.wikibooks.org/wiki/Cyberbotics'_Robot_Curriculum`

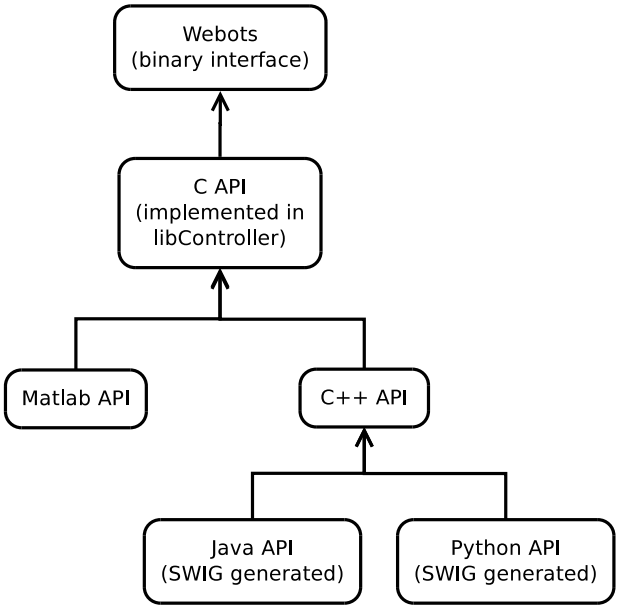


Figure 6.1: Webots APIs Overview

6.4.1 Classes and Methods

C++, Java and Python are object-oriented programming languages and therefore the corresponding Webots APIs are organized in classes. The class hierarchy is built on top of the C API and currently contains about 25 classes and 200 methods (functions).

The Java and Python APIs are automatically generated from the C++ API using SWIG. Therefore the class and method names, as well as the number of parameters and their types, are very similar in these three languages.

The naming convention of the C++/Java/Python classes and methods directly matches the C API function names. For example, for this C function: `double wb_distance_sensor_get_value(WbDeviceTag tag)` there will be a matching C++/Java/Python method called `getValue()` located in a class called `DistanceSensor`. Usually the C++/Java/Python methods have the same parameters as their C API counterparts, but without the `WbDeviceTag` parameter.

6.4.2 Controller Class

The C++/Java/Python controller implementation should be placed in a user-defined class derived from one of the Webots class: `Robot, DifferentialWheels` or `Supervisor`. It is important that the controller class is derived from the same class as that used in Scene Tree, otherwise some methods may not be available or may not work. For example, if in the Scene Tree a robot is of type `DifferentialWheels`, then the corresponding C++/Java/Python controller

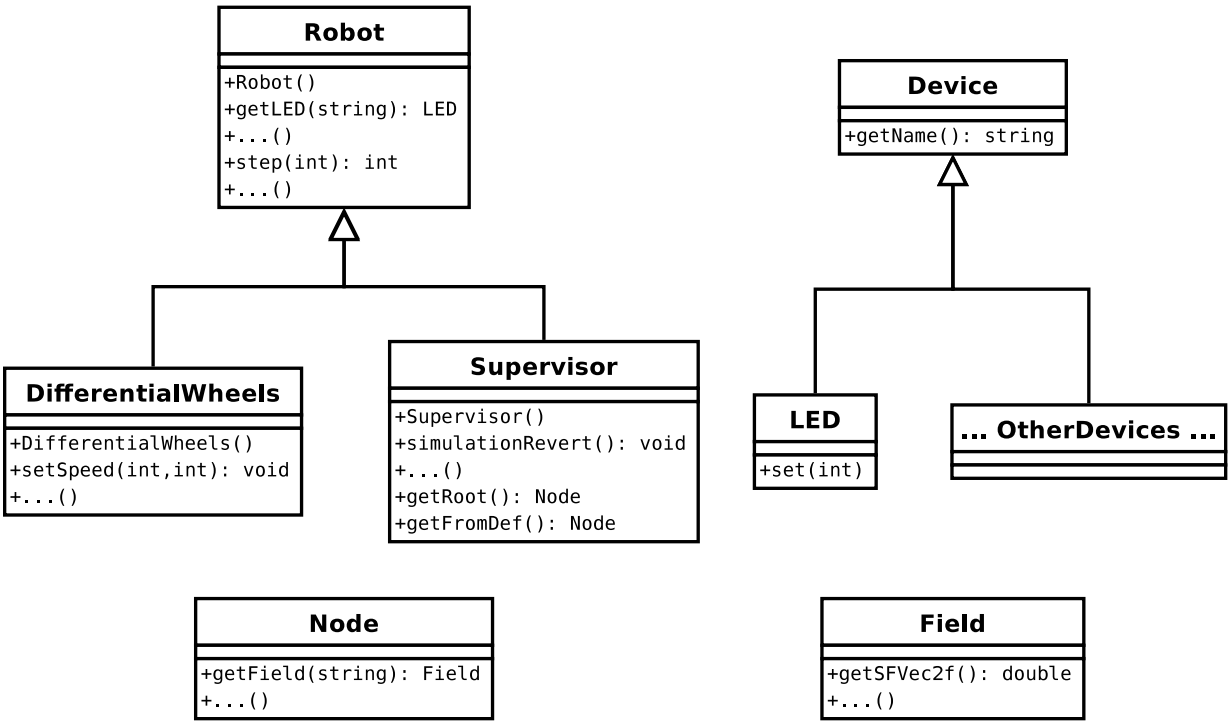


Figure 6.2: A small subset of Webots oriented-object APIs

class must extend the `DifferentialWheels` class. If in the Scene Tree a robot is of type `Supervisor`, then the C++/Java/Python controller class must be derived from the `Supervisor` class, etc.

As you can see in figure 6.2, both `DifferentialWheels` and `Supervisor` are subclasses of the `Robot` class. Hence it is possible to call the `Robot`'s methods, such as, e.g., `step()` or `getLED()`, from the `DifferentialWheels` and `Supervisor` controllers. But it is not possible to call the `Supervisor` methods from a `DifferentialWheels` controller, and vice versa. For example it won't be possible to call `simulationRevert()` from a `DifferentialWheels` controller.

Generally, the user-defined controller class should have a `run()` function that implements the main controller loop. That loop should contains a call to the `Robot`'s `step()` method. Then the only responsibility of the controller's `main()` function is to create an instance of the user-defined controller class, call its `run()` method and finally delete (C++ only) the instance: see examples below. Note that the controller should never create more than one instance of a derived class, otherwise the results are undefined.

Note that unlike the C API, the C++/Java/Python APIs don't have (and don't need) functions like `wb_robot_init()` and `wb_robot_cleanup()`. The necessary initialization and cleanup routines are automatically invoked from the constructor and destructor of the base class.

In C++/Java/Python, each Webots device is implemented as a separate class, there is a `DistanceSensor` class, a `TouchSensor` class, a `RotationalMotor` class, etc. The various

devices instances can be obtained with dedicated methods of the `Robot` class, like `getDistanceSensor()`, `getTouchSensor()`, etc. There is no `WbDeviceTag` in C++/Java/Python.

6.4.3 C++ Example

```
#include <webots/Robot.hpp>
#include <webots/LED.hpp>
#include <webots/DistanceSensor.hpp>

using namespace webots;

#define TIME_STEP 32

class MyRobot : public Robot {
  private:
    LED *led;
    DistanceSensor *distanceSensor;

  public:
    MyRobot() : Robot() {
      led = getLED("ledName");
      distanceSensor = getDistanceSensor("distanceSensorName");
      distanceSensor->enable(TIME_STEP);
    }

    virtual ~MyRobot() {
      // Enter here exit cleanup code
    }

    void run() {
      // Main control loop
      while (step(TIME_STEP) != -1) {
        // Read the sensors
        double val = distanceSensor->getValue();

        // Process sensor data here

        // Enter here functions to send actuator commands
        led->set(1);
      }
    }
};

int main(int argc, char **argv) {
```

```
40   MyRobot *robot = new MyRobot();
41   robot->run();
42   delete robot;
43   return 0;
44 }
```

6.4.4 Java Example

```
1  import com.cyberbotics.webots.controller.*;
2
3  public class MyRobot extends Robot {
4    private LED led;
5    private DistanceSensor distanceSensor;
6    private static final int TIME_STEP = 32;  // milliseconds
7
8    public MyRobot() {
9      super();
10     led = getLED("my_led");
11     distanceSensor = getDistanceSensor("my_distance_sensor");
12     distanceSensor.enable(TIME_STEP);
13   }
14
15   public void run() {
16     // main control loop
17     while (step(TIME_STEP) != -1) {
18       // Read the sensors, like:
19       double val = distanceSensor.getValue();
20
21       // Process sensor data here
22
23       // Enter here functions to send actuator commands, like:
24       led.set(1);
25     }
26
27     // Enter here exit cleanup code
28   }
29
30   public static void main(String[] args) {
31     MyRobot robot = new MyRobot();
32     robot.run();
33   }
34 }
```

6.4.5 Python Example

```
from controller import *

class MyRobot (Robot):
  def run(self):
    led = self.getLed('ledName')
    distanceSensor = self.getDistanceSensor('distanceSensorName
       ')
    distanceSensor.enable(32)

    while (self.step(32) != -1):
      # Read the sensors, like:
      val = distanceSensor.getValue()

      # Process sensor data here

      # Enter here functions to send actuator commands, like:
      led.set(1)

    # Enter here exit cleanup code

robot = MyRobot()
robot.run()
```

6.5 Matlab

The MATLAB™ API for Webots is very similar to the C API. The functions names are identical, only the type and number of parameters differs slightly in some cases. The MATLAB™ functions and prototypes are described in Webots Reference Manual. Note that unlike with the C API, there are no `wb_robot_init()` and `wb_robot_cleanup()` functions in the MATLAB™ API. The necessary initialization and cleanup are automatically carried out respectively before entering and after leaving the controller code.

If the MATLAB™ code uses graphics, it is necessary to call the `drawnow` command somewhere in the control loop in order to flush the graphics.

Here is a simple MATLAB™ controller example:

```
% uncomment the next two lines to use the  desktop
%desktop;
%keyboard;

TIME_STEP = 32;
```

```
6
7  my_led = wb_robot_get_device('my_led');
8  my_sensor = wb_robot_get_device('my_sensor');
9
10 wb_distance_sensor_enable(my_sensor, TIME_STEP);
11
12 while wb_robot_step(TIME_STEP) ~= -1
13   % read the sensors
14   val = wb_distance_sensor_get_value(my_sensor);
15
16   % Process sensor data here
17
18   % send actuator commands
19   wb_led_set(my_led, 1);
20
21   % uncomment the next line if there's graphics to flush
22   % drawnow;
23 end
```

6.5.1 Using the MATLAB™ desktop

In order to avoid cluttering the desktop with too many windows, Webots starts MATLAB™ with the *-nodesktop* option. The *-nodesktop* option starts MATLAB™ without user interface and therefore it keeps the memory usage low which is useful in particular for multi-robot experiments. If you would like to use the MATLAB™ desktop to interact with your controller you just need to add these two MATLAB™ commands somewhere at the beginning of your controller m-file:

```
1 desktop;
2 keyboard;
```

The `desktop` command brings up the MATLAB™ desktop. The `keyboard` stops the execution of the controller and gives control to the keyboard (`K>>` prompt). Then MATLAB™ opens your controller m-file in its editor and indicates that the execution is stopped at the `keyboard` command. After that, the controller m-file can be debugged interactively, i.e., it is possible to continue the execution step-by-step, set break points, watch variable, etc. While debugging, the current values of the controller variables are shown in the MATLAB™ workspace. It is possible to *continue* the execution of the controller by typing `return` at the `K>>` prompt. Finally the execution of the controller can be terminated with `Ctrl-C` key combination.

Once the controller is terminated, the connection with Webots remains active. Therefore it becomes possible to issue Webots commands directly at the MATLAB™ prompt, for example you can interactively issue commands to query the sensors, etc.:

```
>> wb_differential_wheels_set_speed(600, 600);
>> wb_robot_step(1000);
```

```
>> wb_gps_get_values(gps)

ans =

    0.0001    0.0030   -0.6425
>> |
```

It is possible to use additional `keyboard` statements in various places in your `.m` controller. So each time MATLAB™will run into a `keyboard` statement, it will return control to the `K>>` prompt where you will be able to debug interactively.

At this point, it is also possible to restart the controller by calling its m-file from MATLAB™prompt. Note that this will restart the controller only, not the whole simulation, so the current robot and motor positions will be preserved. If you want to restart the whole simulation you need to use the **Revert** button as usual.

6.6 Controller Plugin

The controller functionality can be extended with user-implemented plugins. The purpose of a controller plugin is to facilitate the programming of robot-specific robot windows and remote-control wrappers.

Programming controller plugins rather than programming directly in the controller is more convenient because it increases considerably the modularity and the scalability of the code. For example a robot window can be used for several robots.

6.6.1 Fundamentals

Whatever its language, a controller executable is linked with the Webots controller library (libController) at startup. A controller plugin is a shared library loaded dynamically (at runtime) by libController after a specific event depending on its type.

The figure 6.3 shows an overview of the controller plugin system. In this figure, the dashed arrows shows how the shared libraries are loaded, and the large dash lines represents an Inter-Process Communication (IPC). The IPC between libController and Webots is a pipe (On Windows this is a named pipe, and otherwise a local domain socket). The IPC between libRemoteControl and the real robot is defined by the user (TCP/IP, Serial, etc.).

The system has been designed as follow. Every entities (the controller, the remote control library and the robot window library) should only call the libController interface (Webots API) functions. The controller should not be aware of its robot window and its real robot for modularity reasons. The only exception is about the robot window library which can be aware of the remote control library to initialise and monitor it. This can be done trough the libController API

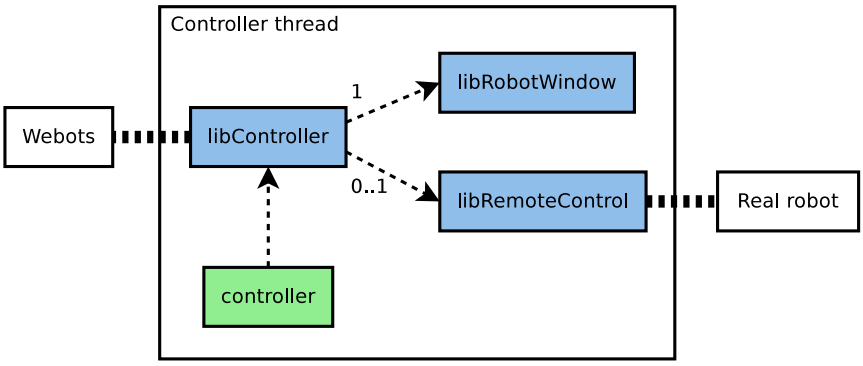


Figure 6.3: Controller plugin overview

through the `wb_robot_get_mode()`, `wb_robot_set_mode()` and the `wb_remote_control_custom_function()` functions. Of course these rules can be easily broken because every entities runs into the same process. However we recommend to respect them to get a good design.

The controller plugins have been designed to be written in C/C++, because the result should be a dynamic library. However it's certainly possible to write them in other languages using a C/C++ wrapper inbetween.

After its loading, some controller plugin functions (entry points) are called by libController. A set of entry points have to be defined to let the controller plugin work smoothly. Some of these entry points are required and some are optional.

The `Robot` node defines the location of the controller plugin through its *robotWindow* and its *remoteControl* fields (cf. reference manual)

The controller plugin run in the main thread of the process (also known as GUI thread): the same as the controller executable. This implies that if an entry point of a plugin is blocking, the controller will also be blocked. And if the plugin crashes, the controller is also crashed.

The search algorithm to convert the *robotWindow* and the *remoteControl* to an existing path is explained in the reference manual.

Each distributed shared library is built thanks to the main Makefile (the same as the one used to build the controllers): `WEBOTS_HOME/resources/Makefile.include`

6.6.2 Robot Window Plugin

A robot window plugin allows the programmer to efficiently create custom robot windows. Robot windows can be opened by double-clicking on the virtual robot, or by selecting the **Robot — Show Robot Window** menu item.

The *robotWindow* field of the `Robot` node specifies a robot window (cf. documentation in the reference manual).

The entry points of a robot window controller plugin are:

- `bool wbw_init()`

  This is the first function called by libController. Its aim is to initialize the graphical user interface without showing it.

- `void wbw_cleanup()`

  This is the last function called by libController. Its aim is to cleanup the library (destroy the GUI, release the memory, store the current library state, etc.)

- `void wbw_pre_update_gui()`

  This function is called before `wbw_update_gui()` to inform its imminent call. Its purpose is to inform that from this moment, the pipe answering from Webots to the controller can receive data. If data is coming from the Webots pipe `wbw_update_gui()` should return as soon as possible.

- `void wbw_update_gui()`

  The aim of this function is to process the GUI events until something is available on the Webots pipe.

- `void wbw_read_sensors()`

  This function is called when it's time to read the sensors values from the Webots API. For example in this function the `wb_distance_sensor_get_value()` function can be called.

- `void wbw_write_actuators()`

  This function is called when it's time to write the actuator commands from the Webots API. For example in this function the `wb_motor_set_position()` function can be called.

- `void wbw_show()`

  This function is called when the GUI should be show. This can occur either when the user double-click on the virtual robot, either when he selects the **Robot — Show Robot Window** menu item, or either at controller startup if the *showRobotWindow* field of the `Robot` node is enabled.

- `void *wbw_robot_window_custom_function(void *)`

  This function can optionally be defined to communicate and pass data from and to the controller program. It is called directly by the user from the controller when executing the `wb_robot_window_custom_function` C function or `Robot::robotWindowCustomFunction` C++ function. You can find more information in the reference manual.

The internal behavior of the `wb_robot_step()` call is the key point to understand how the different entry points of the robot window plugin are called (pseudo-code):

```
wb_robot_step() {
  wbw_write_actuators()
  wbw_pre_update_gui()
  write_request_to_webots_pipe()
  wbw_update_gui() // returns when something on the pipe
  read_request_to_webots_pipe()
  wbw_read_sensors()
}
```

As the Qt libraries are included in Webots (used by the Webots GUI), and all our samples are based on it, we recommend to choose also this framework to create your GUI. The `Makefile.include` mentioned above allows you to efficiently link with the Qt framework embedded in Webots.

The Webots pipe handle (integer id) is available in the WEBOTS_PIPE_IN environment variable.

The Qt utility library helps you to initialize Qt correctly (pipe, window visibility, ...). Refer to the next section for more information related with this library.

If the robot window cannot be loaded (bad path, bad initialization, etc.), a generic robot window is opened instead. This generic robot window displays several sensors and actuators. The source code of this robot window is a good demonstrator of the robot window plugin abilities. All the source code is located there: `WEBOTS_HOME/resources/projects/plugins/robot_windows/generic_window`

Other samples can be found:

`WEBOTS_MODULES_PATH/projects/robots/e-puck/plugins/robot_windows/botstudio`

`WEBOTS_MODULES_PATH/projects/robots/e-puck/plugins/robot_windows/epuck_window`

6.6.3 Qt utility library

In order to facilitate the creation of robot window plugins using the Qt framework, Webots has a utility library allowing to hide the complexity of the management of the robot windows.

This library contains various classes including a subclass of QMainApplication managing the pipe events, a subclass of QMainWindow dealing with the close events, a class to handle Webots standard paths, and a collection of widgets to display the Webots devices. The source code of the generic robot window is a good example illustrating how to use this library.

The location of the qt utility library is `WEBOTS_HOME/resources/projects/libraries/qt_utils`

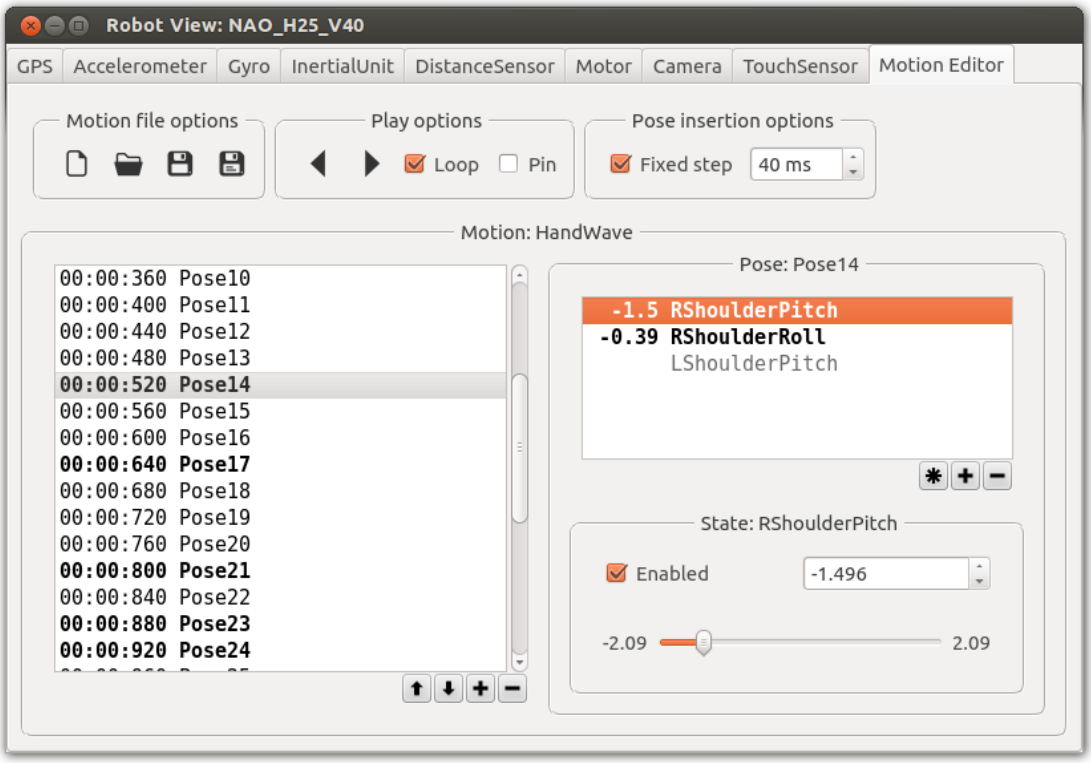


Figure 6.4: Motion editor view

6.6.4 Motion editor

A motion is a chronological sequence of robot poses. A pose is defined by a set of commands (in position) of the robot motors.

The motion is stored in a motion file in a user-readable format. The controller API allows to play easily the motion files on your robot. You can get the complete motion API in the reference manual.

The motion editor (cf. the figure 6.4) is a GUI helping to create motions which can be played by a robot. It is implemented in the Qt utils library, and is embedded inside the generic robot window plugin. This implies that the motion editor is accessible only if the robot is linked (cf. the Robot::robotWindow field) with either the generic window, or on a window using the Qt utils library's corresponding widget.

In the motion editor different fonts and colors are used to identify the status of poses and motor states: modified items are displayed using bold font, disabled states are written in gray, and items with values outside the valid motor position range are written in red.

6.6.5 Remote-control Plugin

A remote-control plugin allow to simply and efficiently create an interface using the Webots API to communicate with a real robot. The main purpose of a remote-control library is to wrap all the Webots API functions used by the robot with a protocol communicating to the real robot. Generally, a program (client) runs on the real robot, and decodes the communication protocol to dialog with the real robot devices.

The remote-control library is initialized when an entity calls the `wb_robot_set_mode()` libController function. This entity is typically libRobotWindow, because it's quite convenient to use the GUI to initialize the communication (i.e. entering the IP address of the robot, etc.)

There are two entry points to the remote-control library:

- `bool wbr_init(WbrInterface *ri)`

  This function is called by libController to initialize the remote control library. It is called after the first `wb_robot_set_mode()` call. The aim of this function is to map the functions given into the `WbrInterface` structure with functions inside the remote-control library.

- `void wbr_cleanup()`

  This function is called by libController to cleanup the library.

The `WbrInterface` structure has several functions (mandatory) which have to be mapped to let the remote-control library run smoothly. Here they are:

- `bool wbr_start(void *arg)`

  This function is called when the connection with the real robot should start. The return value of this function should inform if the connection has been a success or not. The argument matches with the argument given to `wb_robot_set_mode()` when initializing the remote-control. As the robot window library is often responsible in calling `wb_robot_set_mode()`, the structure passed between them should match.

- `void wbr_stop()`

  This function is called when the connection with the real robot should stop. Typically a command stopping the real robot actuators should be sent just before stopping the connection.

- `bool wbr_has_failed()`

  This function is called very often by libController to check the validity of the connection. The value returned by this function should always match with the connection validity.

- `void wbr_stop_actuators()`

  This function is called to stop the actuators of the real robot. This is called when the user pressed the pause button of the simulator.

- `int wbr_robot_step(int period)`

  This function is called when the controller enters in the step loop. The aim of this function is to send the actuator commands and then to read the vaues of the enabled sensors. The timing problem should be solved there. The robot should wait at least *period* milliseconds, and returns the delta time if this *period* is exceeded.

As said above, all the Webots API functionalities that should work with the real robot have to be wrapped into the remote-control library. To achieve this:

- The internal state of the libController has to be setup to match with the current state of the robot.

  Typically, when the value of a sensor is known the corresponding `wbr_sensor_set_value()` has to be called.

- The commands send to the libController have to be wrapped.

  Typically, when the command of an actuator is setup the corresponding `wbr_actuator_set_value()` is called, and has to be sent to the real robot.

The complete definition of the remote control API and of the `WbrInterface` structure is contained in `WEBOTS_HOME/include/controller/c/webots/remote_control.h`

For example, if you want to be able to use the distance sensor of the real robot, you have to wrap the `wbr_set_refresh_rate()` function (to set the internal state of the remote control library to read this distance sensor only when required), and to call `wbr_distance_sensor_set_value()` into the remote-control library when the distance sensor is refreshed (typically into the `wbr_robot_step()` function).

A complete sample (communicating with the e-puck robot using bluetooth) can be found in this directory:

`WEBOTS_MODULES_PATH/projects/robots/e-puck/plugins/remote_controls/e-puck_bluetooth`

6.7 Webots Plugin

Webots functionality can be extended with user-implemented plugins.

6.7.1 Physics Plugin

A *physics* plugin offers the possibility to add custom ODE instructions to the default physics behavior of Webots. For instance it is possible to add or measure forces. By adding forces, it is possible to simulate new types of environments or devices. For example, a wind can be simulated as a constant unidirectional force applied to each object in the world and proportional to the size of the object. The reactor of an airplane can be simulated by adding a force of varying intensity, etc.

Webots distribution comes with some implementations and usage examples for these plugins. You will find more info on this topic in Webots Reference Manual.

Chapter 7

Tutorials

The aim of this chapter is to explain the fundamental concepts of Webots required to create your own simulations. Learning is focused on the modeling of robots and of their environment, as well as on the programming of robot controllers. You will also learn where to find the documentation to go further.

This chapter is suitable for absolute beginners in Webots. A background in programming is nevertheless required. The examples are written in C language. If you are not familiar with the C language, you should be able to understand this chapter anyway, because the C programs below are very simple. Except for programming, you don't need any particular knowledge to go through the tutorials included in this chapter. However a basic background knowledge in robotics, mathematics, modeling and tree representation might turn out to be helpful. Experienced Webots users may skip the first tutorials. However, we would recommend them to read at least the introduction and conclusion of these tutorials.

Each section of this chapter (except the first one and the last one) is a tutorial. Each tutorial has a precise educational objective explained in the first paragraph. The acquired concepts are then summarized in the conclusion subsection. A tutorial is designed as a sequence of interactive steps. The knowledge acquired in a tutorial is often required to continue with the next tutorial. Therefore we strongly recommend you to respect their natural order. Moreover we recommend you to ensure you understood all the concepts of a tutorial before proceeding further.

A Webots PRO license or a 30-days trial license is required to follow all the tutorials. However, an EDU license is sufficient to follow about 95% of this chapter, as it won't allow you to program supervisor processes and physics plugins.

The last section will provide you with some hints to address problems that are not covered in this chapter.

The solutions of the tutorials are located into the `WEBOTS_MODULES_PATH/projects/samples/tutorials` subdirectory of the Webots installation directory.

We hope you will enjoy your first steps with Webots. Meanwhile, we would really appreciate to receive your feedback regarding this chapter.

7.1 Prerequisites

In this section, you will learn how to setup your Webots environment. It is obviously a necessary step to get started with the tutorials.

7.1.1 Install Webots

Webots has to be installed on your computer.

Install Webots by following the instructions given in chapter 1.

7.1.2 Create a directory for all your Webots files

The first step is to create a directory which will contain all your files related to Webots.

From your operating system interface, choose a location on your hard disk where you have the writing rights (for example, your `[My]Documents` *directory). Create there a directory that will contain all your Webots projects, and name it* `my_webots_projects`*.*

7.1.3 Start Webots

You need to learn how to launch Webots.

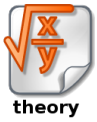
Start Webots by following the instructions given in section 2.2.
If it's the first time you start Webots, a welcome dialog box invites you to choose a demo simulation. Choose any of them, but it's a good opportunity to take a look at our guided tour (also available using the ***Help*** *>* ***Webots Guided Tour...*** *menu).*

Now a simulation is running.

7.1.4 Create a new Project

The freshly created `my_webots_projects` directory will contain all your Webots projects. Your first Webots project will be the tutorials of this chapter. So let's create now a project named `tutorials` which will contain all the simulations of this chapter.

As mentioned earlier in this chapter, the solutions of the tutorials are included in the `WEBOTS_MODULES_PATH/projects/samples/tutorials` subdirectory of Webots. Don't look at it now! Hopefully, your own `tutorials` directory should be pretty similar to that one at the end.



*A **project** is a directory containing all the files related to a set of simulations. It is the highest container in Webots. Two simulations should reside in the same project if they share some content (robots, source code, 3D shapes, etc.).*

*In Webots, open the wizard by selecting the **Wizards** > **New Project Directory...** menu item. From this wizard, follow the instructions to create a new project named `tutorials` in the `my_webots_projects` directory created before.*

From your desktop, open the project directory and observe its subdirectories. We will soon explain the purpose of each directory.

7.1.5 The Webots Graphical User Interface (GUI)

The Webots main window is shown in figure 7.1. Make sure you understand well how the Webots main window is divided into subwindows before continuing. A more detailed description of the Webots GUI is provided in section 2.3.

7.2 Tutorial 1: Your first Simulation in Webots (20 minutes)

In this first tutorial, you will create your first simulation. This simulation will contain a simple environment (a light and an arena with floor and walls), a predefined robot (e-puck) and a controller program that will make the robot move (see figure 7.2). The objective of this tutorial is to familiarize yourself with the user interface and with the basic concepts of Webots.

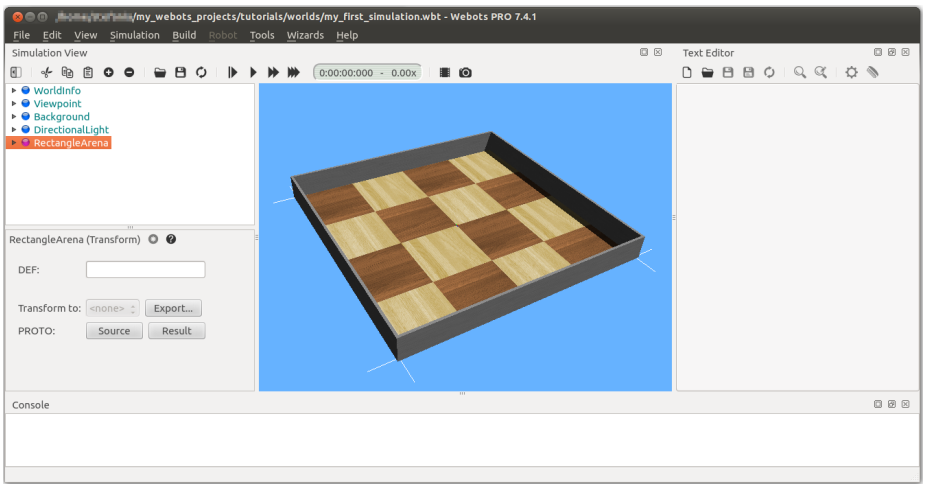


Figure 7.1: The Webots main window splits into four dockable subwindows: the scene tree view on the left hand side (including a panel at the bottom for editing fields values), the 3D view in the center, the text editor on the right hand side, and the console at bottom of the window. Note that some of these subwindows have a toolbar with buttons. The main menus appear on the top of the main window. The virtual time counter and the speedometer are displayed in the right part of the 3D view toolbar. The status text is displayed in the bottom left of the main window.

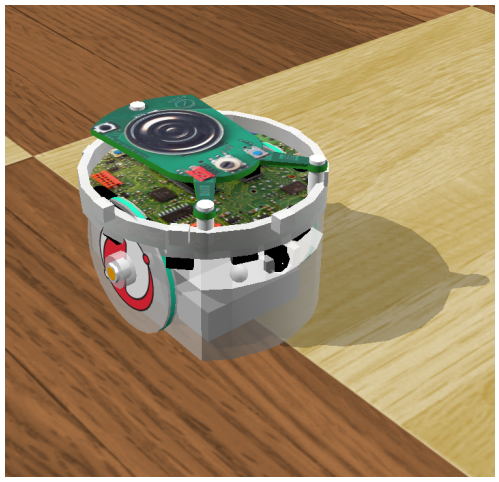
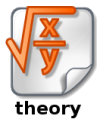


Figure 7.2: What you should see at the end of the tutorial.

7.2.1 Create a new World

In this subsection, we will create a new simulation. The content of a simulation is stored in a world file. This world file contains all the information related to your simulation, i.e. where are the objects, how do they look like, how do they interact with each other, what is the color of the sky, where is the gravity vector, etc.



*A **world** is defined by a tree of **nodes**. Each node has some customizable properties called **fields**. A world is stored in a file having the* `.wbt` *suffix. The format of this file is derived from the **VRML** language, and is human readable. The world files must be stored directly in the project subdirectory called* `worlds`*.*

Webots is currently open and runs an arbitrary simulation.

*Pause the current simulation by clicking on the **Pause** button of the 3D view. The simulation is paused if the virtual time counter on the 3D view toolbar is stable.*

*Create a new world by selecting the **File** > **New World** menu item.*

A new world is now open. For now, the 3D window displays a black screen. This is normal because the scene tree contains only the following fundamental nodes: `WorldInfo` (containing misc global parameters), `Viewpoint` (defining the main camera parameters) and `Background` (defining the background color). As no light and no 3D object are defined, the entire scene is empty and unlit, and so black.

The first step is about to modify the background color.

Modify the background color, by setting up the `skyColor` *field of the* `Background` *node. Choose a blue color (e.g. red = 0.4, green = 0.7 and blue = 1.0) using the color picker at the bottom of the scene tree. The background of the 3D view should be modified accordingly.*

Now we would like to add some light to the scene.

Select the last node of the scene tree view (`Background`*). Click on the* ***Add*** *button at the top of the scene tree view. In the open dialog box, and choose* `New node > DirectionalLight`*. The new node has been added but as there is no 3D object in the scene, the result of this operation is not visible yet.*

Now we would like to add some environment (a floor and some walls). A predefined high-level node called `RectangleArena` is designed to do this task quickly.

Select the last node of the scene tree view (`DirectionalLight`*). Click on the* ***Add*** *button. In the open dialog box, choose* `PROTO (Webots) > objects > floors > RectangleArena`*. The new node has been added and is appearing far away. Use the left click and the wheel of the mouse in the 3D view to choose a better viewpoint.*

It's a good time to improve the scene light.

Modify the following fields of the `DirectionalLight` *node:* `ambientIntensity` *to 1,* `direction` *to [-0.33 -1 -0.5] and* `castShadows` *to TRUE.*

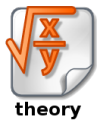
In the scene tree, the fields are displayed in blue if they differ from their default values.

Now your environment should look like the one depicted in the figure 7.1.

Save the new world into your project by selecting the ***File*** *>* ***Save World As...*** *menu item. Using the dialog box save the world into the* `my_webots_projects/tutorials/worlds/my_first_simulation.wbt` *file location.*

Revert the simulation by selecting the ***File*** *>* ***Revert World*** *menu item.*

You can change the viewpoint of the 3D view by using the mouse buttons (left button, right button and the wheel).



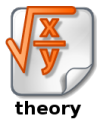
*Webots nodes stored in world files are organized in a tree structure called the **scene tree**. The scene tree can be viewed in two subwindows of the main window: the 3D view (at the center of the main window) is the 3D representation of the scene tree and the scene tree view (on the left) is the hierarchical representation of the scene tree. The scene tree view is where the nodes and the fields can be modified.*

In the 3D view, click on the floor to selected it. When it is selected the floor is surrounded by white lines and the corresponding node is selected in the scene tree view. Now click on the blue sky to unselect the floor.

7.2.2 Add an e-puck Robot

The e-puck is a small robot having differential wheels, 10 LEDs, and several sensors including 8 distance sensors and a camera. In this tutorial we are only interested in using its wheels. We will learn how to use some other e-puck features in the other tutorials.

Now we are going to add an e-puck model to the world. Make sure that the simulation is paused and that the virtual time elapsed is 0.



*When a Webots world is modified with the intention of being saved, it is fundamental that the simulation is first paused and reverted to its initial state, i.e. the virtual time counter on the 3D view toolbar should show 0:00:00:000. Otherwise at each save, the position of each 3D objects can accumulate errors. Therefore, any modification of the world should be performed in that order: **pause, revert, modify and save the simulation**.*

As we don't need to create the e-puck robot from scratch, we will just have to import a special E-puck node (in fact: a PROTO node as the `RectangleArena` we introduced before). A PROTO is an abstract assemblage of several nodes. PROTO nodes are defined in separate `.proto`, but this will be explained in more details later. For now consider the E-puck node as a black box that contains all the necessary nodes to define a e-puck robot.

*Select the last node of the scene tree view (called `RectangleArena`). In order to add the E-puck node, click on the **Add** button at the top of the scene tree view. In the open dialog box, and choose `PROTO (Webots) > robots > e-puck > E-puck (DifferentialWheels)`. Then save the simulation.*

Now if you run the simulation, the robot moves: that's because the robot uses a default controller with that behavior. Please pause and revert the simulation before going on.

You can change the robot's position in the 3D view using the translation and rotation handles (see subsubsection 2.4.3).
Alternatively, the following keyboard shortcuts are available:
SHIFT + left-clicking + drag *to move the robot parallel to the floor;*
SHIFT + mouse-wheel *to move the robot up or down.*
Finally, it is possible to add a force to the robot: CTRL + ALT + left-clicking + drag.

Starting the simulation by pressing the ***Run*** *button will make Webots running the simulation as fast as possible. In order to obtain a real-time simulation speed, the* ***Real-Time*** *button has to be pressed.*

Now we are going to modify the world and decrease the step of the physics simulation: this will increase the accuracy of the simulation.

In the scene tree view, expand the WorldInfo node (the first node). Set its `basicTimeStep` *field to* 16. *Then save the simulation.*

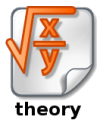
Just after you added the E-puck node, a black window appeared in the upper left corner of the 3D view. It shows the content of Camera nodes, but it will stay black until not explicitly used during a simulation. In order to hide it, you simply have to set the `pixelSize` equal to 0. Then, if you want to re-enable them, you have to set this field value to a positive number. Detailed definitions can be found in chapter 3 of the Reference Manual[1].

In this tutorial we will not use the Camera devices of the E-puck. So we can hide the window by expanding the E-puck node and setting the fields `camera_pixelSize` *to 0. Don't forget to revert the simulation before changing the values and to save it after the modifications.*

[1] `http://www.cyberbotics.com/reference/`

7.2.3 Create a new Controller

We will now program a simple controller that will just make the robot move forwards. As there is no obstacle, the robot will go forwards for ever. Firstly we will create and edit the C controller, then we will link it to the robot.



*A **controller** is a program that defines the behavior of a robot. Webots controllers can be written in the following programming languages: C, C++, Java, Python, Matlab, etc. Note that C, C++ and Java controllers need to be compiled before they can be run as robot controllers. Python and Matlab controllers are interpreted languages so they will run without being compiled. The* `controller` *field of a robot specifies which controller is currently linked with to it. Please take notice that a controller can be used by several robots, but a robot cans use only one controller at a time.*

Each robot controller is executed in a separate child process spawned by Webots. Controllers don't share the same address space, and they can run in different processor cores.

Other languages than C are available but may require a setup. Please refer to the language chapter to setup the other languages (see chapter 4).

Create a new C controller called e-puck_go_forward *using the **Wizards** > **New Robot Controller...** menu. This will create a new* `e-puck_go_forward` *directory in* `my_webots_projects/tutorials/controllers`*. Select the option asking you to open the source file in the text editor.*

The new C source file is displayed in Webots text editor window. This C file can be compiled without any modification, however the code has no real effect. We will now link the E-puck node with the new controller before modifying it.

Link the `E-puck` *node with the* e-puck_go_forward *controller. This can be done in the scene tree view by selecting the* `controller` *field of the E-puck node, then use the field editor at the bottom of the scene tree view: push the **Select...** button and then select* e-puck_go_forward *in the list. Once the controller is linked, save the world.*

Modify the program by inserting an include statement (`#include <webots/differential_wheels.h>`*), and by applying a differential wheels command (*`wb_differential_wheels_set_speed(100, 100)`*):*

```
1  #include <webots/robot.h>
2
3  // Added a new include file
4  #include <webots/differential_wheels.h>
5
6  #define TIME_STEP 64
7
8  int main(int argc, char **argv)
9  {
10   wb_robot_init();
11
12   // set up the speeds
13   wb_differential_wheels_set_speed(100, 100);
14
15   do {
16   } while (wb_robot_step(TIME_STEP) != -1);
17
18   wb_robot_cleanup();
19
20   return 0;
21 }
```

*Save the modified source code (**File** > **Save Text File**), and compile it (**Build** > **Build**). Fix any compilation error if necessary. When Webots proposes to revert the simulation, choose **Yes**.*

If everything is ok, your robot should go forwards.

In the `controllers` *directory of your project, a directory containing the* e-puck_go_forward *controller has been created. The* `e-puck_go_forward` *directory contains an* `e-puck_go_forward` *binary file generated after the compilation of the controller. Note that the controller directory name should match with the binary name.*

7.2.4 Conclusion

We hope you enjoyed creating your first simulation. You have been able to set up your environment, to add a robot and to program it. The important thing is that you learnt the fundamental concepts summarized below:

A Webots world is made of nodes organized in a VRML-like tree structure. A world is saved in a `.wbt` file stored in a Webots project. The project also contains the robot controllers which are the programs that define the robots behavior. Robot controllers can be written in C (or other languages). C controllers have to be compiled before they can be executed. Controllers are linked to robots via the `controller` fields of the robot nodes.

7.3 Tutorial 2: Modification of the Environment (20 minutes)

In this tutorial, we will teach you how to create simple objects in the environment. The first step will be to create a ball which will interact with the environment. We will tackle several concepts related to the nodes: what is their meaning, how to create them, how they have to be affiliated, etc. Moreover we will see how to set up physics.

Several kinds of nodes will be introduced. We won't define each of them precisely. Their detailed definition can be found in chapter 3 of the Reference Manual. Having the nodes chart diagram (chapter 2 of the Reference Manual) in front of you, will also help understanding the nodes inheritance relationship.

7.3.1 A new Simulation

First we create a new simulation based on the one created in Tutorial 1.

Make sure the `my_first_simulation.wbt` world file is open, and that the simulation is paused and is at a virtual time of 0. Using the ***File*** > ***Save World As...*** *menu, save the simulation as `obstacles.wbt`.*

7.3.2 Modification of the Floor

The default `RectangleArena` PROTO defines a simple floor pinned on the statical environment, i.e. without Physics node, and surrounded by walls.

In order to define an object as static, its physics node has not to be set (NULL).

Other pre-built floors are available in the Webots objects library. We will now delete the default arena and add a simple floor that we will manually surround the walls later in this this tutorial.

To remove the `RectangleArena`*, select it in the scene tree view and press the* ***Delete*** *button located in the toolbar.*

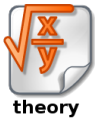
In order to add a different floor PROTO, select the `DirectionalLight` *node and click on the* ***Add*** *button. In the open dialog box, and choose* `PROTO (Webots) > objects > floors > Floor (Solid).`

The newly added `Floor` PROTO has a default size of 10mx10m, but it is possible to adjust its size, its position and texture by changing the corresponding fields.

In the scene tree view select and expand the `Floor`*. Modify the* `size` *fields and set it to* $\{1, 1\}$ *to resize it to 1mx1m.*

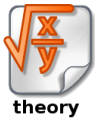
7.3.3 The Solid Node

This subsection introduces the most important node in Webots: the `Solid` node. But let's start with a definition.



A ***rigid body*** *is a body in which deformation can be neglected. The distance between any two given points of a rigid body remains constant in time regardless of external forces exerted on it. Soft bodies and articulated objects are not rigid bodies, e.g. these are not rigid bodies: a rope, a tyre, a sponge and an articulated robot arm. However an articulated entity can be broken into of several undividable rigid bodies. For example a table, a robot finger phalanx or a wheel are undividable rigid bodies.*

The physics engine of Webots is designed for simulating rigid bodies. An important steps, when designing a simulation, is to break up the various entities into undividable rigid bodies.



In Webots there is a direct matching between a rigid body and a ***Solid*** *node. A Solid node (or a node which inherits the Solid node) will be created for each rigid body.*

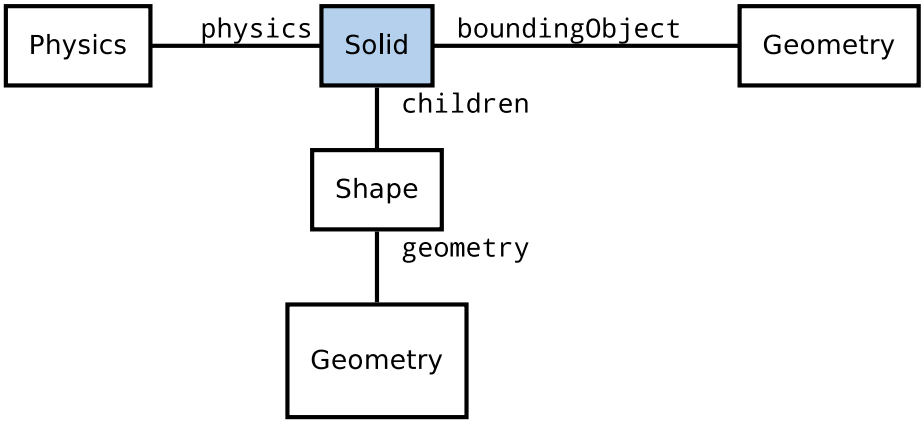


Figure 7.3: The simplest model of a rigid body in Webots having a graphical representation (Shape), a physical bound (boundingObject) and being in the dynamical environment (Physics).

To define a rigid body, you will have to create a Solid node. Inside this node you will find different subnodes corresponding to the characteristics of the rigid body. The figure 7.3 depicts a rigid body and its subnodes. The graphical representation of the Solid is defined by the Shape nodes populating its `children` list. The collision bounds are defined by its `boundingObject` field. The graphical representation and the collision shape are often but not necessarily identical. Finally the `physics` field defines if the object belongs to the dynamical or to the statical environment. All these subnodes are optional, but the `physics` field needs the `boundingObject` to be defined.

The Geometry box (in figure 7.3) stands for any kind of geometrical primitive. In fact it can be substituted by a Sphere, a Box, a Cylinder, etc.

7.3.4 Create a Ball

We will now add a ball to the simulation. That ball will be modeled as a rigid body as shown in the figure 7.3. As Geometry nodes we will use Spheres.

In the scene tree view, select the last node and add a Solid node using the ***Add*** *button. Similarly select the* `children` *field of the Solid node, and add a Shape node to it. Add a Sphere node as the* `geometry` *field of the just created Shape node. Add another Sphere node to the* `boundingObject` *field of the Solid. Finally add a Physics node to the* `physics` *field of the Solid. By modifying the* `translation` *field of the Solid node, place the ball in front of the robot (at* {0, 0.1, -0.2} *for example). Save the simulation. The result is depicted in figure 7.4.*

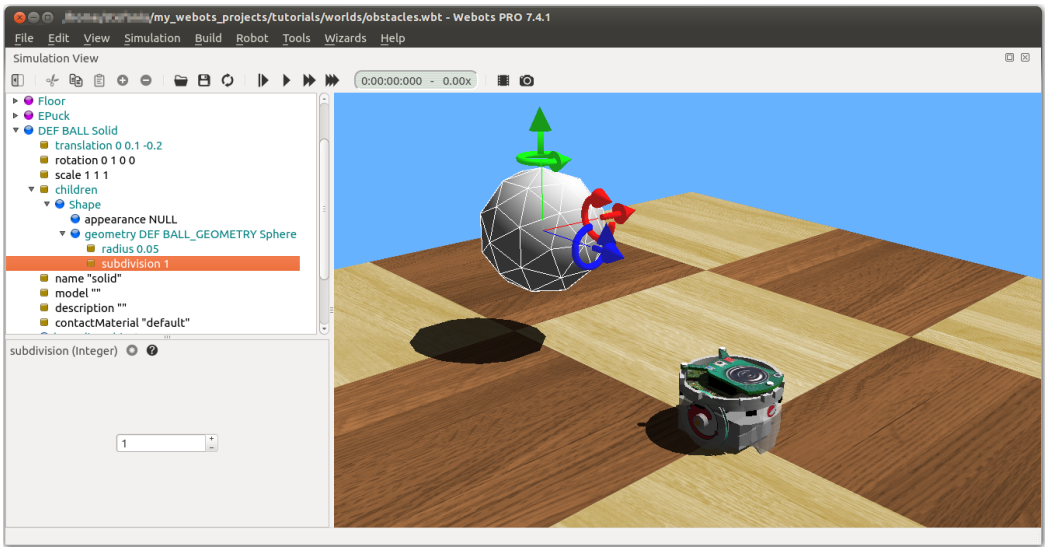


Figure 7.4: Your first rigid body in Webots.

When the simulation is started, the ball hits the floor. You can move the ball by adding a force to it (CTRL + ALT + left-click + drag). The contact points between the ball and the floor can be displayed as cyan lines by enabling the ***View*** > ***Optional Rendering*** > ***Show Contact Points*** *menu item.*

7.3.5 Geometries

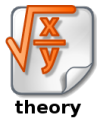
To define the ball, we used the Sphere node in two different contexts: for the graphical representation (`children`) and to define the physical bounds (`boundingObject`). All Geometry node (such as the Sphere node) can be used in a graphical context. However, only a subset of them can be used in a physical context. Take a look at the schema of the chapter 2 of the Reference Manual to now which primitive you can use.

We want now to reduce the size of the Sphere and to increase its graphical quality by increasing the number of triangles used to represent it.

For each Sphere node defining the ball, set its `radius` *field to* 0.05 *and its* `subdivision` *field to* 2. *Refer to the Reference Manual to understand what the* `subdivision` *field stands for.*

7.3.6 DEF-USE mechanism

We will see in this subsection a mechanism which can be useful to avoid redundancy in the world files.



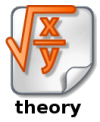
*The **DEF-USE mechanism** allows to define a node in one place and to reuse that definition elsewhere in the Scene Tree. This avoids the duplication of identical nodes and this allows to modify several nodes at the same time. Here is how this works: first a node is labeled with a DEF string, and then copies of this node are reused elsewhere with the USE keyword. Only the fields of the DEF node can be edited, the fields of the USE nodes assume similar values. This mechanism is dependent on the apparition order of the nodes in the world file, because the DEF node should appear first.*

The two Sphere definitions that we have used earlier to define the ball, are redundant. We will now merge these two Spheres into only once using the DEF-USE mechanism.

Select the first Sphere node (the child of the Shape) in the scene tree view. The field editor of the scene tree view allows you to enter the DEF string. Enter "BALL_GEOMETRY". *Select the boundingObject field (containing the second Sphere node), and delete it by using the **Reset to default** button. Then click on the **Add** button, and select the* `USE > BALL_GEOMETRY` *in the dialog box. The result is shown in figure 7.5.*

Now, changing the `radius` *field of the first Sphere node does also modify the* `boundingObject`.

7.3.7 Add Walls



For convenience, the `boundingObject` *field accepts also the Shape node (rather than the Sphere node directly). It would be also possible to use the same DEF-USE mechanism at the Shape level as shown in figure 7.6. For now the best advantage is to use this Shape also directly for graphical purposes. Later this will turn out to be very useful for some sensors.*

In order to verify your progression, implement by yourself four walls to surround the environment. The walls have to be defined statically to the environment, and use as much as possible the DEF-USE mechanism at the Shape level rather than at the Geometry level. Indeed it's more convenient to add an intermediate Shape node in the `boundingObject` field of the Solid node. The best Geometry primitive to implement the walls is the Box node. Only one Shape has to be defined for all the walls. The expected result is shown in figure 7.7.

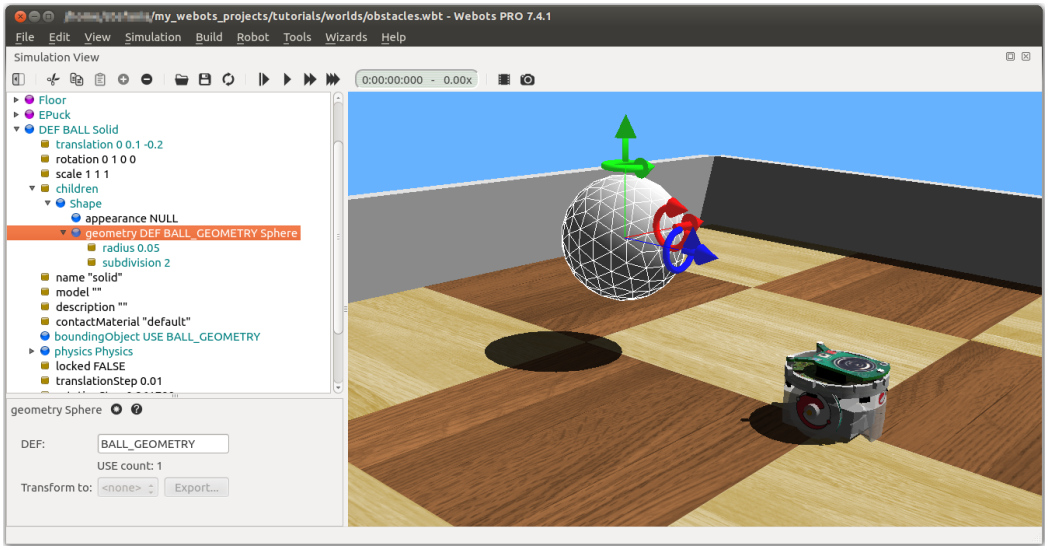


Figure 7.5: DEF-USE mechanism on the Sphere node called "BALL_GEOMETRY".

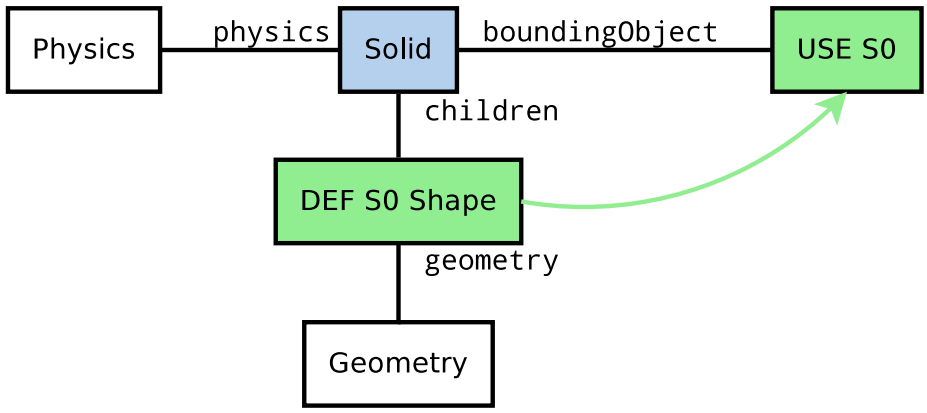


Figure 7.6: DEF-USE mechanism applied on the Shape node of a Solid.

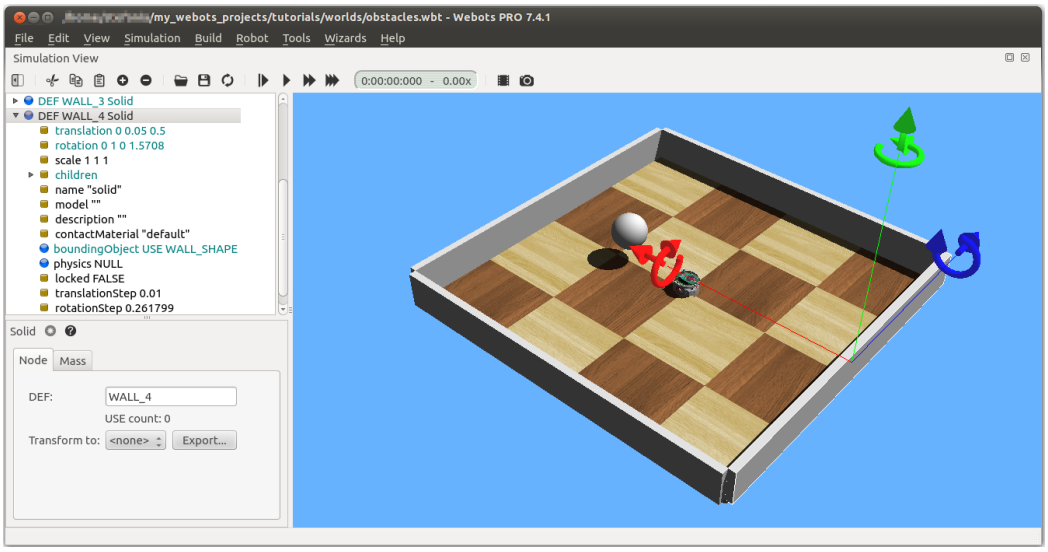
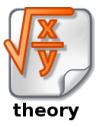


Figure 7.7: The simulation state at the end of this second tutorial.

Add four walls without physics and using only one definition of the Shape node.

The solution is located in the solution directory under the `obstacle.wbt`.

7.3.8 Efficiency



The simulation of rigid bodies is computationally expensive. The simulation speed can be increased by minimizing the number of bounding objects, minimizing the constraints between them (more information about the constraints in the next tutorials), and maximizing the `WorldInfo.basicTimeStep` *field. On each simulation, a* ***trade-off*** *has to be found between the simulation speed and the realism.*

7.3.9 Conclusion

At the end of this tutorial, you are able to create simple environments based on rigid bodies. You are able to add nodes from the scene tree view and to modify their fields. You have a more precise idea of what are the Solid, the Physics, the Shape, the Sphere and the Box nodes. You saw also the DEF-USE mechanism that allows to reduce node redundancy of the scene tree.

7.4 Tutorial 3: Appearance (15 minutes)

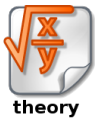
The aim of this tutorial is to familiarize yourself with some nodes related to the graphical rendering. Good looking simulations can be created very quickly when these nodes are used adequately. A good graphics quality does not only enhance the user's experience, it is also essential for simulations where robots perceive their environment (camera image processing, line following, etc.).

The result at the end of this tutorial is shown in figure 7.8.

7.4.1 New simulation

From the results of the previous tutorial, create a new simulation called `appearance.wbt` *by using the* ***File*** > ***Save World As...*** *menu.*

7.4.2 Lights



The lighting of a world is determined by light nodes. There are three types of light nodes: the DirectionalLight, the PointLight and the SpotLight. A DirectionalLight simulates a light which is infinitely far (ex: the sun), a PointLight simulates light emitted from a single point (ex: a light bulb), and a SpotLight simulates a conical light (ex: a flashlight). Each type of light node can cast shadows. You can find their complete documentation in the Reference Manual.

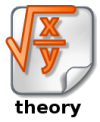
Lights are costly in term of performance. Minimizing the number of lights increases the rendering speed. A maximum of 8 lights is allowed if the shaders are disabled in the Webots preferences. A PointLight is more efficient than a SpotLight, but less than a DirectionalLight. Note finally that casting shadows can reduce the simulation speed drastically.

Your simulation is currently lighted by a PointLight node at the top of the scene. We want to replace this light node by a DirectionalLight node casting shadows.

Remove the PointLight node, and add a new DirectionalLight node instead. Set its `ambientIntensity` *field to* 0.5*, its* `castShadows` *field to* TRUE*, and its* `direction` *field to* {1, -2, 1}.

7.4.3 Modify the Appearance of the Walls

The aim of this subsection is to color the walls with blue.



*The **Appearance** node of the Shape node determines the graphical appearance of the object. Among other things, this node is responsible for the color and texture of objects.*

In the Shape node representing graphically the first wall, add an Appearance node to the `appearance` *field. Then add a Material node to the* `material` *field of the freshly created Appearance node. Set its* `diffuseColor` *field to blue using the color selector. If the DEF-USE mechanism of the previous tutorial has been correctly implemented, all the walls should turn blue.*

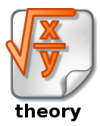
7.4.4 Add a Texture to the Ball

The aim of this subsection is to apply a texture on the ball. A texture on a rolling object can help to appreciate its movement.

Similarly add an Appearance node to the ball. Instead of a Material node, add an ImageTexture node to the `texture` *field of the Appearance node. Add an item to the* `url` *field using the **Add** button. Then set the value of the newly added* `url` *item to* `WEBOTS_MODULES_PATH/projects/default/worlds/textures/bricks.png` *using the file selection dialog.*

The texture URLs must be defined either relative to the `worlds` *directory of your project directory or relative to the default project directory* `WEBOTS_MODULES_PATH/projects/default/worlds`*. In the default project directory you will find textures that are available for every world.*

Open the `bricks.png` *texture in an image viewer while you observe how it is mapped onto the Sphere node in Webots.*



*Textures are mapped onto Geometry nodes according to predefined **UV mapping** functions described in the Reference Manual. A UV mapping function maps a 2D image representation to a 3D model.*

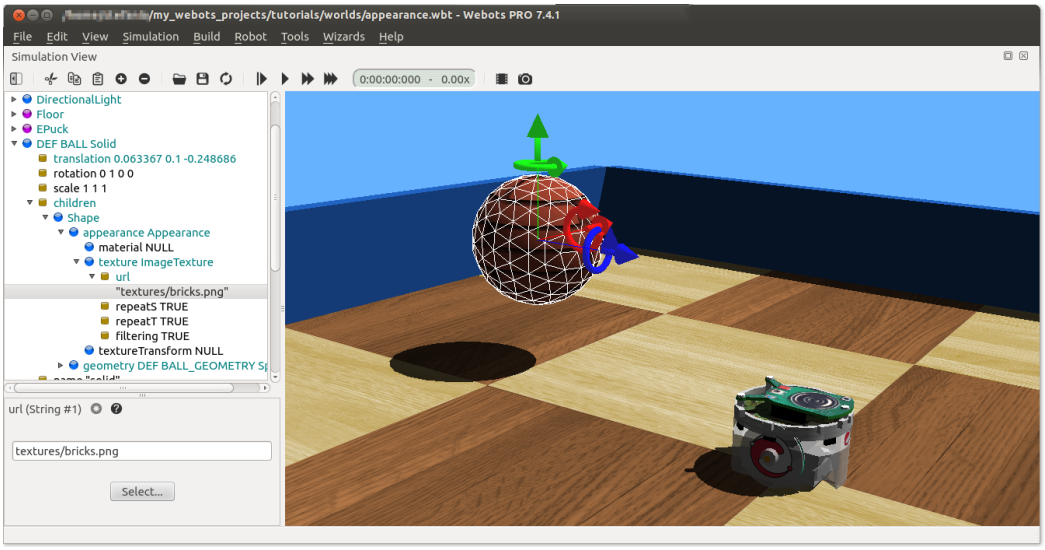


Figure 7.8: Simulation after having setup the Light and the Appearance nodes.

7.4.5 Rendering Options

Webots offers several rendering modes available in the **View** menu.

View the simulation in wireframe mode by using the ***View*** > ***Wireframe Rendering*** *menu item. Then restore the plain rendering mode:* ***View*** > ***Plain Rendering****.*

7.4.6 Conclusion

In this tutorial, you have learnt how to set up a good looking environment using the Appearance node and the light nodes.

You can go further on this topic by reading the detailed description of these nodes in the Reference Manual. The subsection 9.3.7 will give you a method to efficiently setup these nodes.

7.5 Tutorial 4: More about Controllers (20 minutes)

Now we start to tackle the topics related to programming robot controllers. We will design a simple controller that avoids the obstacles created in the previous tutorials.

This tutorial will introduce you to the basics of robot programming in Webots. At the end of this chapter, you should understand what is the link between the scene tree nodes and the controller API, how the robot controller has to be initialized and cleaned up, how to initialize the robot

devices, how to get the sensor values, how to command the actuators, and how to program a simple feedback loop.

This chapter only addresses the correct usage of Webots functions. The study of robotics algorithms is beyond the goals of this tutorial and so this won't be addressed here. Some rudimentary programming knowledge is required to tackle this chapter (any C tutorial should be a sufficient introduction). At the end of the chapter, links to further robotics algorithmics are given.

7.5.1 New World and new Controller

Save the previous world as `collision_avoidance.wbt`.

Create a new C controller called `e-puck_avoid_collision` *using the wizard. Modify the* `controller` *field of the E-puck node in order to link it to the new controller.*

7.5.2 Understand the e-puck Model

Controller programming requires some information related to the e-puck model. For doing the collision avoidance algorithm, we need to read the values of its 8 infra-red distance sensors located around its turret, and we need to actuate its two wheels. The way that the distance sensors are distributed around the turret and the e-puck direction are depicted in figure 7.9.

The distance sensors are modeled by 8 DistanceSensor nodes in the hierarchy of the robot. These nodes are referenced by their `name` fields (from "ps0" to "ps7"). We will explain later how these nodes are defined. For now, simply note that a DistanceSensor node can be accessed through the related module of the Webots API (through the `webots/distance_sensor.h` include file). The values returned by the distance sensors are scaled between 0 and 4096 (piecewise linearly to the distance), while 4096 means that a big amount of light is measured (an obstacle is close) and 0 means that no light is measured (no obstacle).

In the same way, the e-puck root node is a DifferentialWheel node and can be access by the `webots/differential_wheel.h` include file. The speed is given in a number of ticks/seconds where 1000 ticks correspond to a complete rotation of the wheel. The values are clamped between -1000 and 1000.

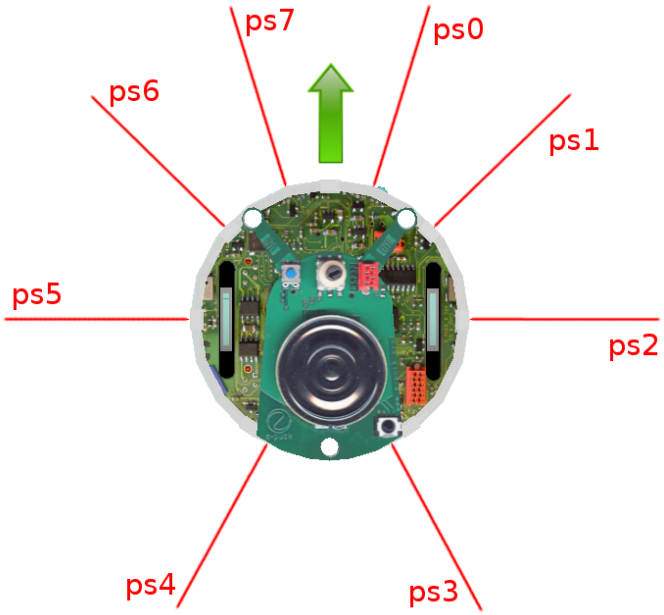
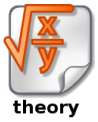


Figure 7.9: Top view of the e-puck model. The green arrow indicates the front of the robot. The red lines represent the directions of the infrared distance sensors. The string labels corresponds to the distance sensor names.



*The **controller API** is the programming interface that gives you access to the simulated sensors and actuators of the robot. For example, including the* `webots/distance_sensor.h` *file allows to use the* `wb_distance_sensor_*()` *functions and with these functions you can query the values of the DistanceSensor nodes. The documentation on the API functions can be found in Chapter 3 of the Reference Manual together with the description of each node.*

7.5.3 Program a Controller

We would like to program a very simple collision avoidance behavior. You will program the robot to go forwards until an obstacle is detected by the front distance sensors, and then to turn towards the obstacle-free direction. For doing that, we will use the simple feedback loop depicted in the UML state machine in figure 7.10.

The complete code of this controller is given in the next subsection.

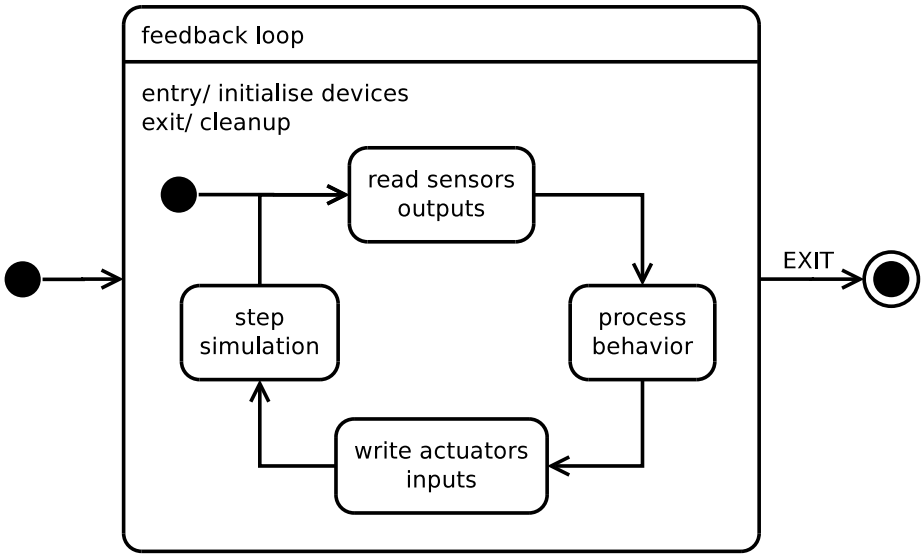


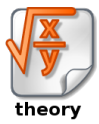
Figure 7.10: UML state machine of a simple feedback loop

At the beginning of the controller file, add the include directives corresponding to the Robot, the DifferentialWheels and the DistanceSensor nodes in order to be able to use the corresponding API (documented in chapter 3 of the Reference Manual):

```
1 #include <webots/robot.h>
2 #include <webots/differential_wheels.h>
3 #include <webots/distance_sensor.h>
```

Just after the include statements add a macro that defines the duration of each physics step. This macro will be used as argument to the `wb_robot_step()` *function, and it will also be used to enable the devices. This duration is specified in milliseconds and it must be a multiple of the value in the* `basicTimeStep` *field of the WorldInfo node.*

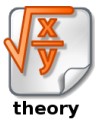
```
1 #define TIME_STEP 64
```



The function called `main()` *is where the controller program starts execution. The arguments passed to main() are given by the* `controllerArgs` *field of the Robot node. The Webots API has to be initialized using the* `wb_robot_init()` *function and it has to be cleaned up using the* `wb_robot_cleanup()` *function.*

Write the prototype of the `main()` *function as follows:*

```
1  // entry point of the controller
2  int main(int argc, char **argv)
3  {
4    // initialize the Webots API
5    wb_robot_init();
6    // initialize devices
7    // feedback loop
8    while (1) {
9      // step simulation
10     int delay = wb_robot_step(TIME_STEP);
11     if (delay == -1) // exit event from webots
12       break;
13     // read sensors outputs
14     // process behavior
15     // write actuators inputs
16   }
17   // cleanup the Webots API
18   wb_robot_cleanup();
19   return 0; //EXIT_SUCCESS
20 }
```



A robot device is referenced by a `WbDeviceTag`*. The* `WbDeviceTag` *is retrieved by the* `wb_robot_get_device()` *function. Then it is used as first argument in every function call concerning this device.*
A sensor such as the DistanceSensor has to be enabled before use. The second argument of the enable function defines at which rate the sensor will be refreshed.

Just after the comment "// initialize devices", *get and enable the distance sensors as follows:*

```
// initialize devices
int i;
WbDeviceTag ps[8];
char ps_names[8][4] = {
  "ps0", "ps1", "ps2", "ps3",
  "ps4", "ps5", "ps6", "ps7"
};

for (i=0; i<8; i++) {
  ps[i] = wb_robot_get_device(ps_names[i]);
  wb_distance_sensor_enable(ps[i], TIME_STEP);
}
```

In the main loop, just after the comment "// read sensors outputs", *read the distance sensor values as follows:*

```
// read sensors outputs
double ps_values[8];
for (i=0; i<8 ; i++)
  ps_values[i] = wb_distance_sensor_get_value(ps[
      i]);
```

In the main loop, just after the comment "// process behavior", *detect if a collision occurs (i.e. the value returned by a distance sensor is bigger than a threshold) as follows:*

```
// detect obstacles
bool left_obstacle =
  ps_values[0] > 100.0 ||
  ps_values[1] > 100.0 ||
  ps_values[2] > 100.0;
bool right_obstacle =
  ps_values[5] > 100.0 ||
  ps_values[6] > 100.0 ||
  ps_values[7] > 100.0;
```

Finally, use the information about the obstacle to actuate the wheels as follows:

```
// init speeds
double left_speed  = 500;
double right_speed = 500;
// modify speeds according to obstacles
if (left_obstacle) {
  // turn right
  left_speed  -= 500;
  right_speed += 500;
}
else if (right_obstacle) {
  // turn left
  left_speed  += 500;
  right_speed -= 500;
}
// write actuators inputs
wb_differential_wheels_set_speed(left_speed,
   right_speed);
```

*Compile your code by selecting the **Build** > **Build** menu item. Compilation errors are displayed in red in the console. If there are any, fix them and retry to compile. Revert the simulation.*

7.5.4 The Controller Code

Here is the complete code of the controller detailed in the previous subsection.

```
#include <webots/robot.h>
#include <webots/differential_wheels.h>
#include <webots/distance_sensor.h>

// time in [ms] of a simulation step
#define TIME_STEP 64

// entry point of the controller
int main(int argc, char **argv)
{
  // initialize the Webots API
  wb_robot_init();

```

```
14  // internal variables
15  int i;
16  WbDeviceTag ps[8];
17  char ps_names[8][4] = {
18    "ps0", "ps1", "ps2", "ps3",
19    "ps4", "ps5", "ps6", "ps7"
20  };
21
22  // initialize devices
23  for (i=0; i<8 ; i++) {
24    ps[i] = wb_robot_get_device(ps_names[i]);
25    wb_distance_sensor_enable(ps[i], TIME_STEP);
26  }
27
28  // feedback loop
29  while (1) {
30    // step simulation
31    int delay = wb_robot_step(TIME_STEP);
32    if (delay == -1) // exit event from webots
33      break;
34
35    // read sensors outputs
36    double ps_values[8];
37    for (i=0; i<8 ; i++)
38      ps_values[i] = wb_distance_sensor_get_value(ps[i]);
39
40    // detect obstacles
41    bool left_obstacle =
42      ps_values[0] > 100.0 ||
43      ps_values[1] > 100.0 ||
44      ps_values[2] > 100.0;
45    bool right_obstacle =
46      ps_values[5] > 100.0 ||
47      ps_values[6] > 100.0 ||
48      ps_values[7] > 100.0;
49
50    // init speeds
51    double left_speed  = 500;
52    double right_speed = 500;
53
54    // modify speeds according to obstacles
55    if (left_obstacle) {
56      left_speed  -= 500;
57      right_speed += 500;
58    }
```

```
59      else if (right_obstacle) {
60        left_speed  += 500;
61        right_speed -= 500;
62      }
63
64      // write actuators inputs
65      wb_differential_wheels_set_speed(left_speed, right_speed);
66    }
67
68    // cleanup the Webots API
69    wb_robot_cleanup();
70    return 0; //EXIT_SUCCESS
71  }
```

7.5.5 Conclusion

Here is a quick summary of the key points you need to understand before going on:

- The controller entry point is the `main()` function like any standard C program.
- No Webots function should be called before the call of the `wb_robot_init()` function.
- The last function to call before leaving the main function is the `wb_robot_cleanup()` function.
- A device is referenced by the `name` field of its device node. The reference of the node can be retrieved thanks to the `wb_robot_get_device()` function.
- Each controller program is executed as a child process of the Webots process. A controller process does not share any memory with Webots (except the cameras images) and it can run on another CPU (or CPU core) than Webots.
- The controller code is linked with the `libController` dynamic library. This library handles the communication between your controller and Webots.

The section 6.1 explains in more detail controller programming. We invite you to read carefully this section before going on.

7.6 Tutorial 5: Compound Solid and Physics Attributes (15 minutes)

The aim of this chapter is to explore in more detail the physics simulation by creating a solid with several bounding objects: a dumbbell made of two spheres and one cylinder. The expected result is depicted in figure 7.11.

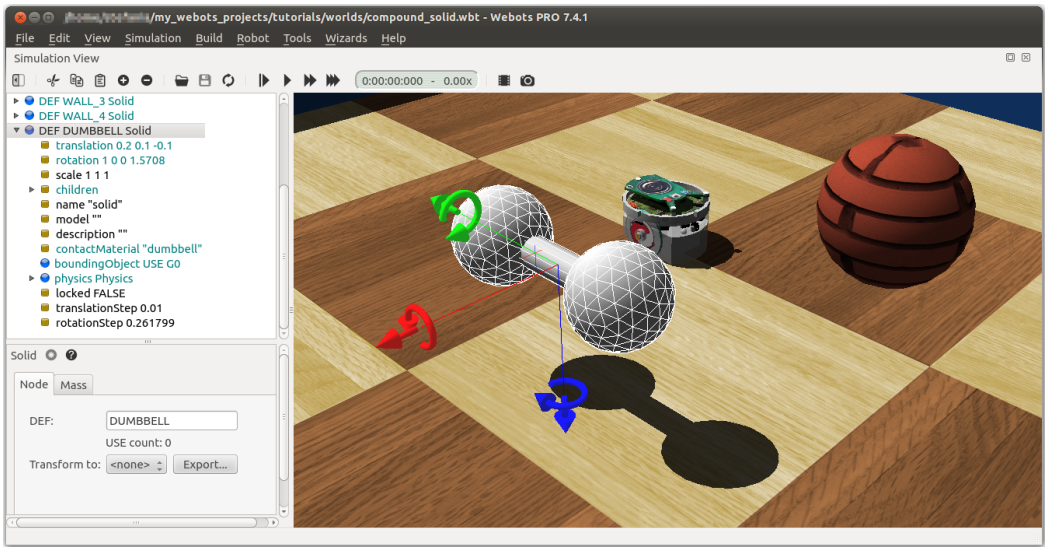


Figure 7.11: Expected result at the end of the tutorial about compound solids.

7.6.1 New simulation

Start from the results of the previous tutorial and create a new simulation called `compound_solid.wbt` *by using the menu* ***File*** > ***Save World As...***.

7.6.2 Compound Solid

It is possible to build Solid nodes more complex than what we have seen before by aggregating Shape nodes. In fact, both the physical and the graphical properties of a Solid can be made of several Shape nodes. Moreover each Shape node can be placed in a Transform node in order to change its relative position and orientation. Group nodes can also be used to group several subnodes.

We want to implement a dumbbell made of a handle (Cylinder) and of two weights (Sphere) located at each end of the handle. The figure 7.12 depicts the Solid nodes and its subnodes required to implement the dumbbell.

Create the dumbbell by following the figure 7.12. Create the handle first without placing it in a Transform node (so the handle axis will have the same direction as the y*-axis of the solid). The handle should have a length of 0.1 m and a radius of 0.01 m. The weights should have a radius of 0.03 m and a subdivision of 2. The weights can be moved at the handle extremities thanks to the* `translation` *field of their Transform nodes.*

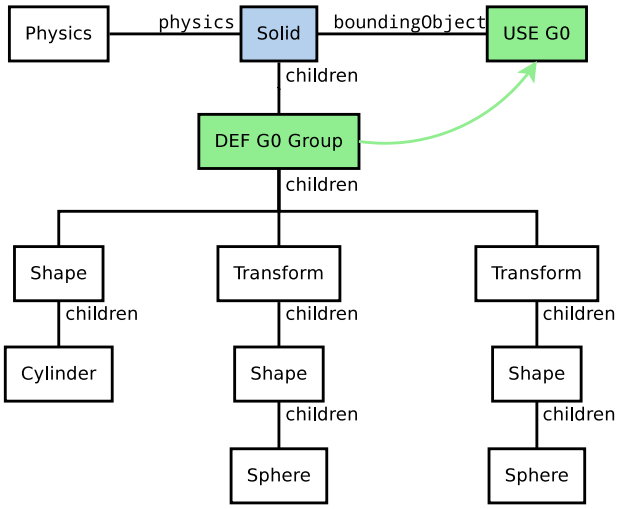
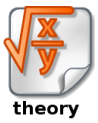


Figure 7.12: Representation of the subnodes of a compound solid made of several transformed geometries.

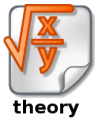
7.6.3 Physics Attributes

The aim of this subsection is to learn how to set some simple physics properties for a Solid node. The Physics node contains fields related to the physics of the current rigid body (Solid).



*The **mass** of a Solid node is given by its* `density` *or* `mass` *field. Only one of these two fields can be specified at a time (the other should be set to* -1*). When the* `mass` *is specified, it defines the total mass of the solid (in [kg]). When the* `density` *is specified, its value (in [kg/m3]) is multiplied by the volume of the bounding objects, and the product gives the total mass of the solid. A density of 1000 [kg/m^3] corresponds to the density of water (default value).*

Set the mass of the dumbbell to 2 *[kg]. The density is not used and should be set to* -1.

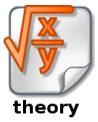


*By default, the **center of mass** of a Solid node is set at its origin (defined by the translation field of the solid). The center of mass can be modified using the* `centerOfMass` *field of the Physics node. The center of mass is specified relatively to the origin of the Solid.*

Let's say that one of the weights is heavier than the other one. Move the center of mass of the dumbbell of 0.01 *[m] along the* y*-axis.*

Note that when the solid is selected, the center of mass is represented in the 3D view by a coordinate system which is darker than the coordinate system representing the solid center.

7.6.4 The Rotation Field



The `rotation` *field of the Transform node determines the rotation of this node (and of its children) using the* ***Euler axis and angle*** *representation. A* ***Euler axis and angle*** *rotation is defined by four components. The first three components are a unit vector that defines the rotation axis. The fourth component defines the rotation angle about the axis (in [rad]).*
The rotation occurs in the sense prescribed by the right-hand rule.

Modify the rotation of the Solid node of the dumbbell in order to move the handle's axis (y*-axis) parallel to the ground. A unit axis of* (1, 0, 0) *and an angle of* $\pi/2$ *is a possible solution.*

7.6.5 How to choose bounding Objects?

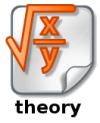
As said before, minimizing the number of bounding objects increases the simulation speed. However choosing the bounding objects primitives carefully is also crucial to increase the simulation speed.

Using a combination of Sphere, Box, Capsule and Cylinder nodes for defining objects is very efficient. Generally speaking, the efficiency of these primitives can be sorted like this: Sphere $>$ Box $>$ Capsule $>$ Cylinder. Where the Sphere is the most efficient. But this can be neglected for a common usage.

The IndexdedFaceSet geometry primitive can also be used in a bounding object. But this primitive is less efficient than the other primitives listed above. Moreover its behavior is sometimes buggy. For this reasons, we don't recommend using the IndexdedFaceSet when another solution using a combination of the other primitives is possible.

Grounds can be defined using the Plane or the ElevationGrid primitives. The Plane node is much more efficient than the ElevationGrid node, but it can only be used to model a flat terrain while the ElevationGrid can be used to model an uneven terrain.

7.6.6 Contacts



When two solids collide, ***contacts*** *are created at the collision points. ContactProperties nodes can be used to specify the desired behavior of the contacts (e.g. the friction between the two solids).*
Each solid belongs to a material category referenced by their `contactMaterial` *field (*"default"*by default). The WorldInfo node has a* `contactProperties` *field that stores a list of ContactProperties nodes. These nodes allow to define the contact properties between two categories of Solids.*

We want now to modify the friction model between the dumbbell and the other solids of the environment.

Set the `contactMaterial` *field of the dumbbell to* "dumbbell". *In the WorldInfo node, add a ContactProperties node between the* "default" *and* "dumbbell" *categories. Try to set the* `coulombFriction` *field to* 0 *and remark that the dumbbell slides (instead of rotating) on the floor because no more friction is applied.*

7.6.7 basicTimeStep, ERP and CFM

The most critical parameters for a physics simulation are stored in the `basicTimeStep`, `ERP` and `CFM` fields of the WorldInfo node.

The `basicTimeStep` field determines the duration (in [ms]) of a physics step. The bigger this value is, the quicker the simulation is, the less precise the simulation is. We recommend values between *8* and *16* for a regular use of Webots.

It's more difficult to explain the behavior of the `ERP` and `CFM` fields. These values are directly used by the physics engine to determine how the constraints are solved. The default values are well defined for a regular use of Webots. We recommend to read the Reference Manual and the documentation of ODE[2] (physics engine used in Webots) to understand completely their purpose.

7.6.8 Minor physics Parameters

There are also other physics parameters which are less useful in a regular use of Webots. A complete description of these parameters can be found in the Reference Manual. Remark simply that the Physics, WorldInfo and ContactProperties nodes contains other fields.

[2] `http://ode-wiki.org/wiki/index.php?title=Manual`

Search in the Reference Manual how to add a linear damping on all the objects, how to unset the auto-disable feature and how to use the inertia matrix.

7.6.9 Conclusion

You are now able to build a wide range of solids including those being composed of several rigid bodies. You know that a Geometry node can be moved and rotated if it is included in a Transform node. You are aware about all the physics parameters allowing you to design robust simulations. The next step will be to create your own robot.

You can test your skills by creating common objects such as a table.

7.7 Tutorial 6: 4-Wheels Robot

The aim of this tutorial is to create your first robot from scratch. This robot will be made of a body, four wheels, and two distance sensors. The result is depicted in figure 7.13. The figure 7.14 shows the robot from a top view.

7.7.1 New simulation

Save the world of the previous tutorial as `4_wheels_robot.wbt`.

Remove the nodes defining the e-puck, the ball, the dumbbell and the contact properties. The ground, the walls and the lighting are kept.

7.7.2 Separating the Robot in Solid Nodes

Some definitions are required before giving rules to create a robot model.

The set containing the Solid node and all its derived nodes is called the *solid nodes*. A similar definition is applied for the Device, Robot, Joint and Motor nodes. You can get more information about the node hierarchy in the Reference Manual. Note that the solid nodes and device nodes is close but don't match perfectly.

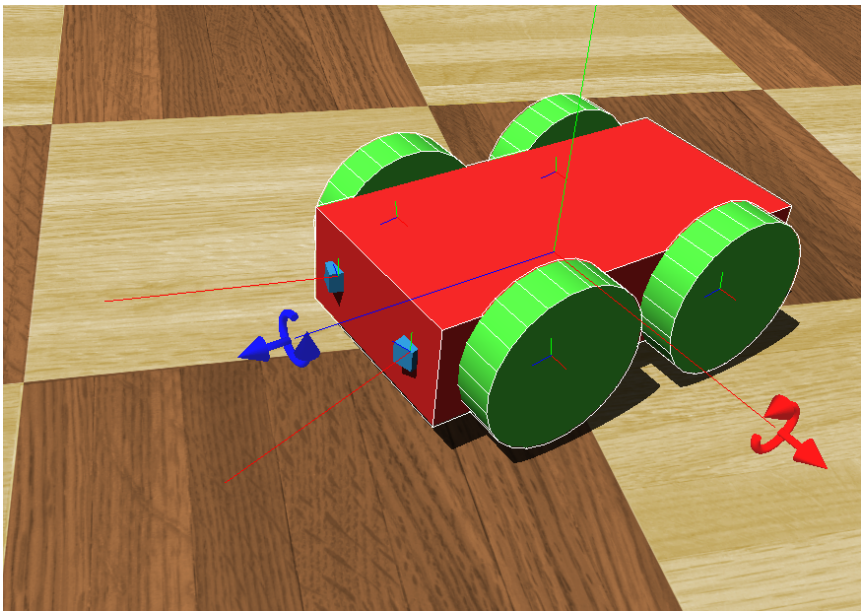


Figure 7.13: 3D view of the 4 wheels robot. Note that the coordinate system representations of the robot body and of its wheels are oriented the same way. Their +x-vector (in red) defines the left of the robot, their +y-vector (in green) defines the top of the robot, and their +z-vector (in blue) defines the front of the robot. The distance sensors are oriented in a different way, their +x-vector indicates the direction of the sensor.

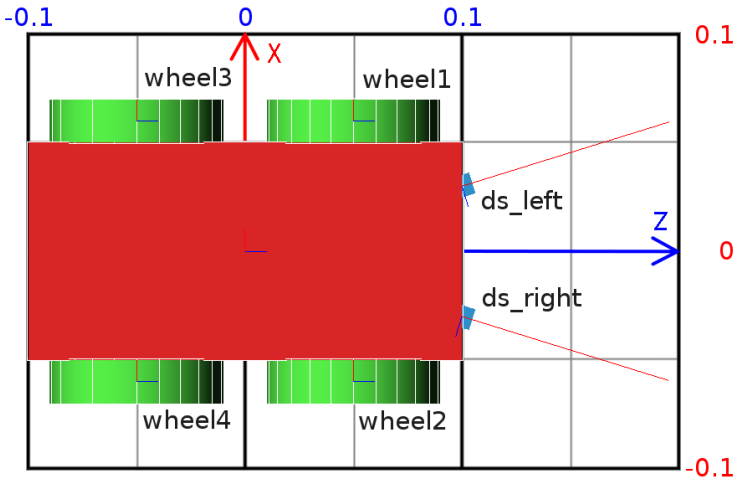
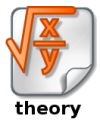
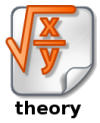


Figure 7.14: Top view of the 4 wheels robot. The grid behind the robot has a dimension of 0.2 x 0.3 [m]. The text labels correspond to the name of the devices.



The main structure of a robot model is a tree of solid nodes linked together. The root node of this tree should be a robot node. The solid are linked together by joint nodes. A device node should be the direct child of either a robot node, either a solid node or a joint node.



A joint node is used to add one (or two) degree(s) of freedom (DOF), between its parent and its child. The direct parent and child of a joint node are both solid nodes.
The nodes derived from Joint allow to create different kind of constraints between the linked solid nodes. The most used in robotics is the HingeJoint allowing to model amongst others rotational motors including wheels.
A joint node can be monitored or actuated by adding respectively a Position-Sensor node, or a motor node to its device *field.*

Having these rules in mind, we can start to design the node hierarchy used to model the robot. The first step is to determine which part of the robot should be modeled as a solid node.

In our example, this operation is quite obvious. The robot has 4 DOF corresponding to the wheel motors. It can be divided in five solid nodes: the body and the four wheels.

Depending on the expected application of the robot model, reducing the number of DOF when modeling could be important to get an efficient simulation. For example, when modeling a caster wheel, a realistic approach implies to model 2 DOF. But if this degree of precision is useless for the simulation, a more efficient approach can be found. For example, to model the caster wheel as a Sphere having a null friction coefficient with the ground.

The second step is to determine which solid node is the robot node (the root node). This choice is arbitrary, but a solution is often much easier to implement. For example, in the case of an humanoid robot, the robot node would be typically the robot chest, because the robot symmetry facilitates the computation of the joint parameters.

In our case, the body box is obviously the better choice. The figure 7.15 depicts the solid nodes hierarchy of the robot.

At the end of the scene tree, add a Robot node having four HingeJoints having a Solid child. Please refer to figure 7.15.

Add a Shape node containing a Box geometry to the Robot node. Set the color of the Shape to red. Use the Shape to define also the `boundingObject` *field of the Robot node. The dimension of the box is* (0.1, 0.05, 0.2). *Add a Physics node to the Robot. The figure 7.16 represents all the nodes defining the robot. So far only the direct children nodes of the root Robot node are implemented.*

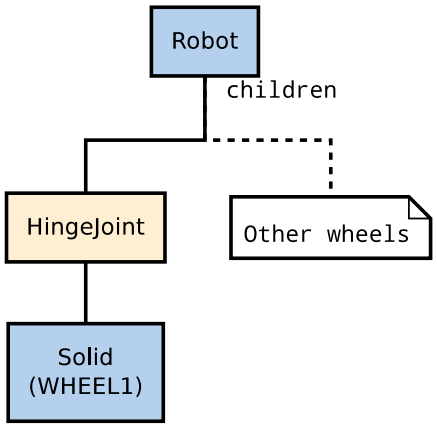


Figure 7.15: High level representation of the 4 wheels robot

7.7.3 HingeJoints

The initial position of the Wheel is defined by the translation and the rotation fields of the Solid node. While the rotation origin (anchor) and the rotation axis (axis) are defined by the optional HingeJointParameters child of the HingeJoint node.

For the first wheel, the Solid translation should be defined to *(0.06, 0, 0.05)* in order to define the relative gap between the body and the wheel. The HingeJointParameters anchor should also be defined to *(0.06, 0, 0.05)* to define the rotation origin (relatively to the body). Finally the HingeJointParameters axis should define the rotation axis. In our case it's along the x-axis (so *(1, 0, 0)*).

Add a HingeJointParameters node, and enter the field values as described above. Some signs have obviously to be updated for other wheels.

We want now to implement the cylinder shape of the wheels. As the Cylinder node is defined along the *y*-axis, a Transform node should encapsulate the Shape to rotate the Cylinder along the along the *x*-axis.

Complete the missing nodes to get the same structure as the one depicted in figure 7.16. Don't forget the Physics nodes. Rotate the Transform node by an Euler axis and angle of (0, 0, 1, Pi/2) *in order to inverse the* x*-axis and the* y*-axis. The Cylinder should have a* `radius` *of* 0.04 *and a* `height` *of* 0.02*. Set the color of the wheels to green.*

In order to be able to actuate the wheels, add a RotationalMotor to each HingeJoint, and set their `name` *fields from* "wheel1" *to* "wheel4"*. These labels will be used to reference the wheels from the controller.*

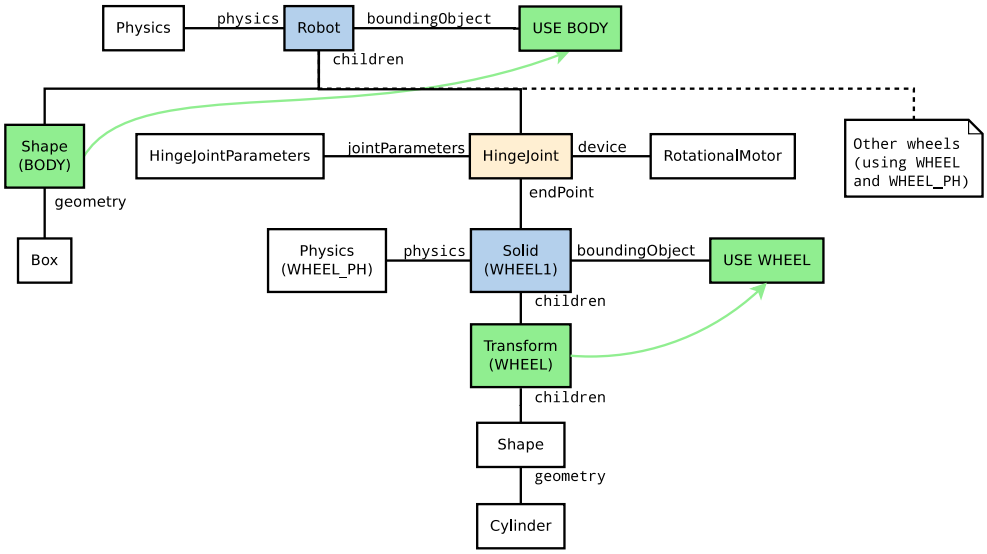


Figure 7.16: Low level representation of the 4 wheels robot

7.7.4 Sensors

The last part of the robot modeling is to add the two distance sensors to the robot. This can be done by adding two DistanceSensor nodes as direct children of the Robot node. Note that the distance sensor acquires its data along the $+x$-axis. So rotating the distance sensors in order to point their x-axis outside the robot is necessary (see the figure 7.14).

Add the two distance sensors as explained above. The distance sensors are at an angle to 0.3 [rad] with the robot front vector. Set their `type` *field to "sonar". Set their graphical and physical shape to a cube (not transformed) having a edge of* 0.01 *[m]. Set their color to blue. Set their* `name` *field according to the labels of figure 7.14.*

7.7.5 Controller

In the previous tutorials, you learnt how to setup a feedback loop and how to read the distance sensor values. However actuating the RotationalMotor nodes is new. The following note explain how to proceed.

To program the rotational motors, the first step is to include the API module corresponding to the RotationalMotor node:

```
#include <webots/motor.h>
```

Then to get the references of the RotationalMotor nodes:

```
// initialize motors
WbDeviceTag wheels[4];
char wheels_names[4][8] = {
  "wheel1", "wheel2", "wheel3", "wheel4"
};
for (i=0; i<4 ; i++)
  wheels[i] = wb_robot_get_device(wheels_names[i
     ]);
```

A motor can be actuated by setting its position, its velocity, its acceleration or its force (cf. Reference Manual). Here we are interested in setting its velocity. This can be achieve by setting its position at infinity, and by bounding its velocity:

```
double speed = -1.5; // [rad/s]
wb_motor_set_position(wheels[0], INFINITY);
wb_motor_set_velocity(wheels[0], speed);
```

Implement a controller called `4_wheels_collision_avoidance` *moving the robot and avoiding obstacles by detecting them by the distance sensors.*
Note that the `lookupTable` *field of the DistanceSensor nodes indicates which values are returned by the sensor (cf. Reference Manual).*
Don't forget to set the `controller` *field of the Robot node to indicate your new controller.*
As usual a possible solution of this exercise is located in the tutorials directory.

7.7.6 Conclusion

You are now able to design simple robot models, to implement them and to create their controllers.

More specifically you learnt the different kind of nodes involved in the building of the robot models, the way to translate and rotate a solid relatively to another, the way that a rotational motor is actuated by the controller.

7.8 Tutorial 7: Using ROS

This tutorial explains how to implement a Webots controller as a ROS node. This process is exemplified by describing how we built the `joystick` controller located in `WEBOTS_MODULES_PATH/projects/languages/ros/controllers/joystick`.

We assume that you installed ROS groovy on your computer as explained in the online ROS installation tutorial. As the ROS joy package is currently defined on Linux only, you won't be able to compile this controller example on other platforms.

7.8.1 Creating a Webots project that contains a ROS package

The `joystick` controller is a Webots controller written in C++ and implemented as a ROS node. It subscribes to the *joy/joy* topic of the `joy_node` (see ROS `joy` package) in order to listen to the joystick state. The relevant line in `webots_joystick_node.cpp` is:

```
ros::Subscriber sub=nh.subscribe("joy", 10, joy_callback);
```

which prompts ten times per second the callback function *joycall_back* to transform the joystick sensed values into a robot motion command.

We now describe the actions to setup the controller directory `WEBOTS_MODULES_PATH/projects/languages/ros/controllers/joystick` both on ROS and Webots side (as provided in your Webots distribution). We are to recreate the corresponding project based on its bare bones: the world file `WEBOTS_MODULES_PATH/projects/languages/ros/worlds/joystick.wbt`, the source file `WEBOTS_MODULES_PATH/projects/languages/ros/controller/catkin_ws/src/webots_joystick/src/webots_joystick_node.cpp` and the ROS launcher file `WEBOTS_MODULES_PATH/projects/languages/ros/controller/joy.launch`. Note that `joy.launch` is used in `webots_joystick_node.cpp` to launch the ROS node `joy_node` as child process:

```
// launch the joy ROS node
    int roslaunch=fork();
    if (roslaunch==0) { // child process
      execlp("roslaunch","roslaunch","joy.launch",NULL);
      return 0;
    }
```

We will be done once we will have provided Webots with an executable file in `WEBOTS_MODULES_PATH/projects/languages/ros/controllers/joystick` whose name matches the controller directory name, i.e. `joystick` (which is also the name specified in `joystick.wbt`). As we want this executable to be a ROS a node, we will create and build a ROS package called `webots_joystick` and copy the resulting executable in `WEBOTS_MODULES_PATH/projects/languages/ros/controllers/joystick`.

Prior to package construction, we create and setup a *catkin* workspace from which we will run most of the build process through the `catkin_make` command.

Create a project directory called `my_ros`, with subdirectories `worlds` and `controllers/joystick`. Copy `WEBOTS_MODULES_PATH/projects/languages/ros/worlds/joystick.wbt` into `my_ros/worlds`. You can perform these actions by opening a terminal and typing:

```
$ mkdir -p ~/my_ros/worlds
$ mkdir -p ~/my_ros/controllers/joystick
$ cp $WEBOTS_MODULES_PATH/projects/languages/ros/worlds/
   joystick.wbt ~/my_ros/worlds/
```

Copy the file `WEBOTS_MODULES_PATH/projects/languages/ros/controllers/joystick/joy.launch` into `my_ros/controllers/joystick`:

```
$ cp $WEBOTS_MODULES_PATH/projects/languages/ros/
   controllers/joystick/joy.launch ~/my_ros/controllers/
   joystick
```

We will use catkin, the official ROS build system (see ROS tutorials for catkin basics).

Create and init a catkin workspace. You can perform these actions through a terminal by typing:

```
$ cd ~/my_ros/controllers/joystick
$ mkdir -p catkin_ws/src
$ cd catkin_ws/src
$ catkin_init_workspace
```

Install the joy package.

```
$ sudo apt-get install ros-groovy-joystick-drivers
$ rosdep install joy
```

Create a ROS package named `webots_joystick` *specifying dependency on* `roscpp` *and* `joy`.

```
$ cd ~/my_ros/controllers/joystick/catkin_ws/src
$ catkin_create_pkg webots_joystick roscpp joy
```

Calling `catkin_create_pkg` *must have created the directory* `webots_joystick` *with the subdirectories* `webots_joystick/src` *and* `webots_joystick/include` *plus two files:* `webots_joystick/CMakeLists.txt` *and* `webots_joystick/package.xml`. *The former is a CMake file that tells catkin how to build the ROS package, the latter is a description of the package where you can specify the package dependencies, the version number, the author name, the maintainer name, etc.*

If you want to use the ROS command line tools (`roscd`, `rosls`, `rospack`, `...`*) to navigate and get information about the created package then you need to call* `catkin_make` *at the root of the catkin workspace and source the file* `devel/setup.bash`:

```
$ cd ~/my_ros/controllers/joystick/catkin_ws
$ catkin_make
$ source devel/setup.bash
```

Now the output of the command `rospack find webots_joystick` *should be*

```
~/my_ros/controllers/joystick/catkin_ws/src/
   webots_joystick
```

The information on package first level dependencies which are displayed after the `rospack depends1 webots_joystick` *command should read as*

```
joy
roscpp
```

Copy the original `.cpp` *controller file into your package resource directory.*

```
$ cd ~/my_ros/controllers/joystick/catkin_ws/src/
   webots_joystick/src
$ cp $WEBOTS_MODULES_PATH/projects/languages/ros/
   controllers/joystick/catkin_ws/src/webots_joystick/
   src/webots_joystick_node.cpp .
```

In the file `webots_joystick/CMakeLists.txt` *uncomment the line*

```
#add_executable(webots_joystick_node src/
   webots_joystick_node.cpp)
```

and append the following lines

```
set(WEBOTS_HOME $ENV{WEBOTS_HOME})
add_definitions(-I${WEBOTS_HOME}/include/controller/cpp
   -I${WEBOTS_HOME}/include -Wall -I${WEBOTS_HOME}/
   include/controller/c -DLINUX)
find_library(CPP_CONTROLLER_LIBRARY CppController ${
   WEBOTS_HOME}/lib)
find_library(C_CONTROLLER_LIBRARY Controller ${
   WEBOTS_HOME}/lib)
target_link_libraries(webots_joystick_node ${
   catkin_LIBRARIES} ${C_CONTROLLER_LIBRARY} ${
   CPP_CONTROLLER_LIBRARY})
```

These lines tell catkin where to find the Webots controller libraries and to link the `webots_joystick_node` *against them. (The comments indicate where to paste these lines appropriately; the distributed CMakeLists.txt file shows you the right places.)*

Build the webots_joystick package. Then copy the resulting ROS node executable at the root of `controllers/joystick` *and rename it appropriately.*

```
$ cd ~/my_ros/controllers/joystick/catkin_ws
$ catkin_make
$ cp devel/lib/webots_joystick/webots_joystick_node ~/
   my_ros/controllers/joystick/joystick
```

Calling `catkin_make` *created the directories* `catkin_ws/build` *and* `catkin_ws/devel`*. You should source* `catkin_ws/devel/setup.bash` *if you want to use ROS built-in commands to manage the* `webots_joystick` *package.*

Have a look at the file `WEBOTS_MODULES_PATH/projects/languages/ros/controllers/joystick/Makefile`*. This file allows you to (re)compile the* `joystick` *controller from Webots build editor (edit the source file in Webots build editor and hit the build button). You may take inspiration from it when building other Webots-ROS projects.*

In case you need to configure your joystick, please refer to the ROS joy tutorials.

7.8.2 Conclusion

You should be able to run the `joystick` you just built as the original one (open `~/my_ros/worlds/joystick.wbt` and hit the play button). You hence achieved a fully functional Webots controller implemented as a ROS node. Exploring further Webots C/C++ and Python APIs will allow you to integrate larger ROS frameworks.

7.9 Going Further

You have now enough knowledge to set up your own simulation Webots. You are able to design and implement a robot, to setup its controller and to design an environment.

However the Webots possibilities go much beyond this. Reading the documentation related with your application in the User Guide[3] or in the Reference Manual is the first step to extend your knowledge.

The algorithmic to develop your controllers is not explained in the Webots documentation. However another tutorial known as ”curriculum” tackle some famous robot programming problems through a sequence of exercises using the e-puck robot and the C language.

[3] `http://www.cyberbotics.com/guide/`

Chapter 8

Robots

8.1 Using the e-puck robot

In this section, you will learn how to use Webots with the e-puck robot (figure 8.1). E-puck is a miniature mobile robot originally developed at the EPFL for teaching purposes by the designers of the successful Khepera robot. The hardware and software of e-puck is fully open source, providing low level access to every electronic device and offering unlimited extension possibilities. The official e-puck web site[1] provides the most up-to-date information about this robot. E-puck is also available for purchase from Cyberbotics Ltd.

8.1.1 Overview of the robot

E-puck was designed to fulfill the following requirements:

- *Elegant design*: the simple mechanical structure, electronics design and software of e-puck is an example of a clean and modern system.
- *Flexibility*: e-puck covers a wide range of educational activities, offering many possibilities with its sensors, processing power and extensions.
- *Simulation software*: e-puck is integrated with Webots simulation software for easy programming, simulation and remote control of the (physical) robot.
- *User friendly*: e-puck is small and easy to setup on a tabletop next to a computer. It doesn't need any cables, providing optimal working comfort.
- *Robustness and maintenance*: e-puck is resilient under student use and is simple to repair.
- *Affordable*: the price tag of e-puck is friendly to university budgets.

E-puck is equipped with a large number of devices, as summarized in table 8.1.

[1] `http://www.e-puck.org`

Figure 8.1: The e-puck robot at work

8.1.2 Simulation model

The e-puck model in Webots is depicted in figure 8.2. This model includes support for the differential wheel motors (encoders are also simulated), the infra-red sensors for proximity and light measurements, the accelerometer, the camera, the 8 surrounding LEDs, the body and front LEDs; the other e-puck devices are not yet simulated in the current model. Besides standard e-puck devices, the model also provides two slots that can be used to extend the functionality and to equip the robot with additional devices. In particular, the ground sensors module extension of the real e-puck robot is modeled in Webots to provide 3 optional infra-red sensors pointing to the ground in front of the robot. The table 8.2 displays the names of the simulated devices which are to be used as an argument of the function `wb_robot_get_device()` (see the Robot section of Reference Manual[2]).

The e-puck dimensions and speed specifications are shown in table 8.3. The functions `wb_differential_wheels_set_speed()`, `wb_differential_wheels_get_left_encoder()` and `wb_differential_wheels_get_right_encoder()` will allow you to set the speed of the robot and to use its encoders.

As is the case for any Differential Wheels robot set at its default position in Webots, the forward direction of the e-puck is given by the negative z-axis of the world coordinates. This is also the direction the eye of the camera is looking to; in keeping with the VRML standard, the direction vector of the camera is pointing in the opposite direction, namely the direction of the positive z-axis. The axle's direction is given by the positive x-axis. Proximity sensors, light sensors and LEDs are numbered clockwise; their location and orientation are shown in table 8.3 and table 8.4. The last column of table 8.4 lists the angles between the negative x-axis and the direction

[2] `http://www.cyberbotics.com/reference/`

Feature	Description
Size	7.4 cm in diameter, 4.5 cm high
Weight	150 g
Battery	about 3 hours with the provided 5Wh LiION rechargeable battery
Processor	Microchip dsPIC 30F6014A @ 60MHz (about 15 MIPS)
Motors	2 stepper motors with 20 steps per revolution and a 50:1 reduction gear
IR sensors	8 infra-red sensors measuring ambient light and proximity of obstacles in a 4 cm range
Camera	color camera with a maximum resolution of 640x480 (typical use: 52x39 or 640x1)
Microphones	3 omni-directional microphones for sound localization
Accelerometer	3D accelerometer along the X, Y and Z axis
LEDs	8 red LEDs on the ring and one green LED on the body
Speaker	on-board speaker capable of playing WAV or tone sounds.
Switch	16 position rotating switch
Bluetooth	Bluetooth for robot-computer and robot-robot wireless communication
Remote Control	infra-red LED for receiving standard remote control commands
Expansion bus	expansion bus to add new possibilities to your robot
Programming	C programming with the GNU GCC compiler system
Simulation	Webots EDU or PRO facilitates the programming of e-puck with a powerful simulation, remote control and cross-compilation system.

Table 8.1: e-puck features

of the devices, the plane zOx being oriented counter-clockwise. Note that the proximity sensors and the light sensors are actually the same devices of the real robot used in a different mode, so their direction coincide. Proximity sensors responses are simulated in accordance with the lookup table in figure 8.3; this table is the outcome of calibration performed on the real robot.

The resolution of the camera was limited to 52x39 pixels, as this is the maximum rectangular image with a 4:3 ratio which can be obtained from the remote control interface with the real robot.

The standard model of the e-puck is provided in the `E-puck.proto` PROTO file which is located in the `WEBOTS_MODULES_PATH/projects/robots/e-puck/protos` directory of the Webots distribution (see also `E-puckDistanceSensor.proto` PROTO file and `E-puckGroundSensors.proto` PROTO file); you will find complete specifications in it. The two PROTO fields `groundSensorSlot` and `turretSlot` have been included in the simulation model in order to support extension modules.

Several simulation examples are located in the `WEBOTS_MODULES_PATH/projects/robots/e-puck/worlds` directory of the Webots distribution. The `e-puck_line.wbt` world (see figure 8.5) especially examplifies the use of ground sensors. Ground sensors can be added to a real e-puck robot by inserting a special extension card with three sensors just below the

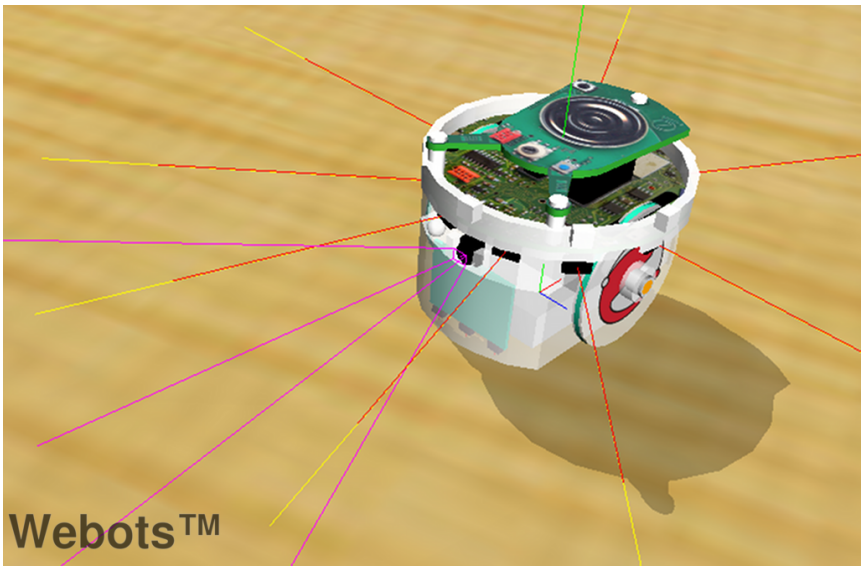


Figure 8.2: The e-puck model in Webots

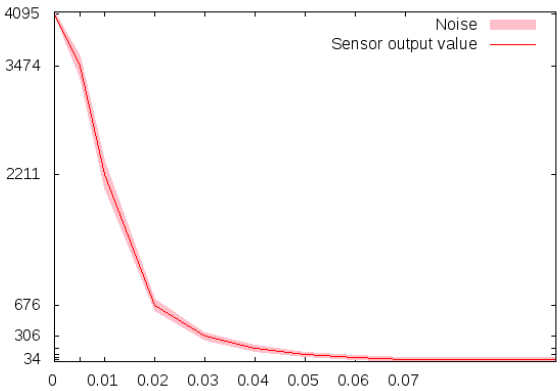


Figure 8.3: Proximity sensor response against distance

Device	Name
Differential wheels	differential wheels
Proximity sensors	ps0 to ps7
Light sensors	ls0 to ls7
LEDs	led0 to led7 (e-puck ring), led8 (body) and led9 (front)
Camera	camera
Accelerometer	accelerometer
Ground sensors (extension)	gs0, gs1 and gs2

Table 8.2: Devices names

Main specifications	Values
Robot radius	37 mm
Wheel radius	20.5 mm
Axle length	52 mm
Encoder resolution	159.23
Speed unit	0.00628 rad/s
Maximum angular speed	1000 units

Table 8.3: e-puck specifications

camera of the robot. These sensors are actually simple infra-red sensors which allow the e-puck robot to see the color level of the ground at three locations in a line across its front. The `groundSensorSlot` field of the standard E-puck PROTO is expressly provided for equipping the simulated e-puck robot with the ground sensors extension modeled in the `E-puckGroundSensors` PROTO. This is particularly useful for implementing line following behaviors. The `e-puck_line` controller program contains the source code for a simple line following system which, as an exercise, can be improved upon to obtain the behavior demonstrated in the `e-puck_line_demo.wbt` demo, in which the e-puck robot is able to follow the line drawn on the floor, but also to avoid obstacles and return to the line following behavior

Device	x (m)	y (m)	z (m)	Orientation (rad)
ps0	0.010	0.033	-0.030	1.27
ps1	0.025	0.033	-0.022	0.77
ps2	0.031	0.033	0.00	0.00
ps3	0.015	0.033	0.030	5.21
ps4	-0.015	0.033	0.030	4.21
ps5	-0.031	0.033	0.00	3.14159
ps6	-0.025	0.033	-0.022	2.37
ps7	-0.010	0.033	-0.030	1.87
camera	0.000	0.028	-0.030	4.71239

Table 8.4: Devices orientations

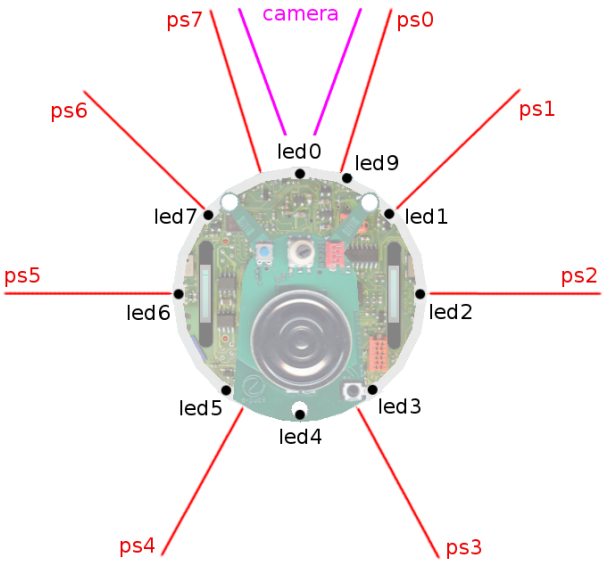


Figure 8.4: Sensors, LEDs and camera

afterwards. This model was contributed by Jean-Christophe Zufferey from the EPFL, who sets up a series of exercises with Webots and extended e-puck robots.

The directory `WEBOTS_MODULES_PATH/projects/samples/curriculum` contains a rich collection of simulations involving the e-puck robot. You will find inside it all the worlds and controllers corresponding to the exercices of Cyberbotics robotics curriculum[3]. Written in collaboration with professors and master students of EPFL, Cyberbotics curriculum is an educational document intended for all level of learnings in robotics. It addresses a dozen of topics ranging from finite state automata to particle swarm optimization, all illustated through the real or the simulated e-puck robot; you can browse it here[4].

The e-puck models of Webots distribution are open source and you are welcome to modify them. If you develop a useful modification and would like to share it, please let us know so that we can improve these models using your contribution.

8.1.3 Control interface

Control window

When opening a world containing an e-puck robot, Webots displays the e-puck control window (which also appears when you double-click on the e-puck robot). This window is depicted in figure 8.6. It allows visualizing the devices of the robot. The distance measurements are displayed in red, outside the body of the robot. The light measurements are displayed in yellow, above the

[3] `http://www.cyberbotics.com/publications/RiE2011.pdf`
[4] `http://www.cyberbotics.com/curriculum`

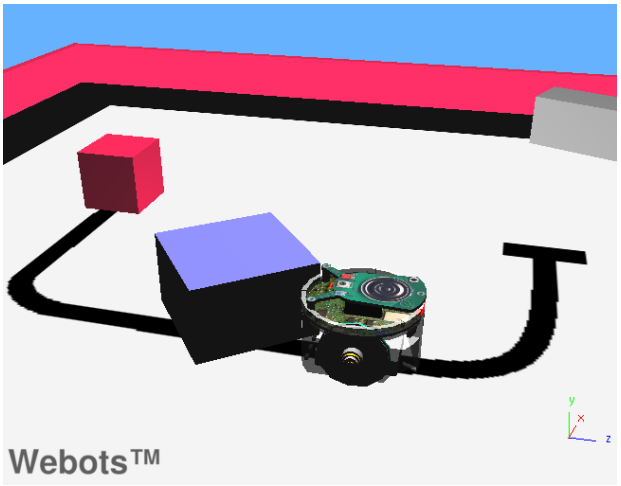


Figure 8.5: An e-puck extension for line following

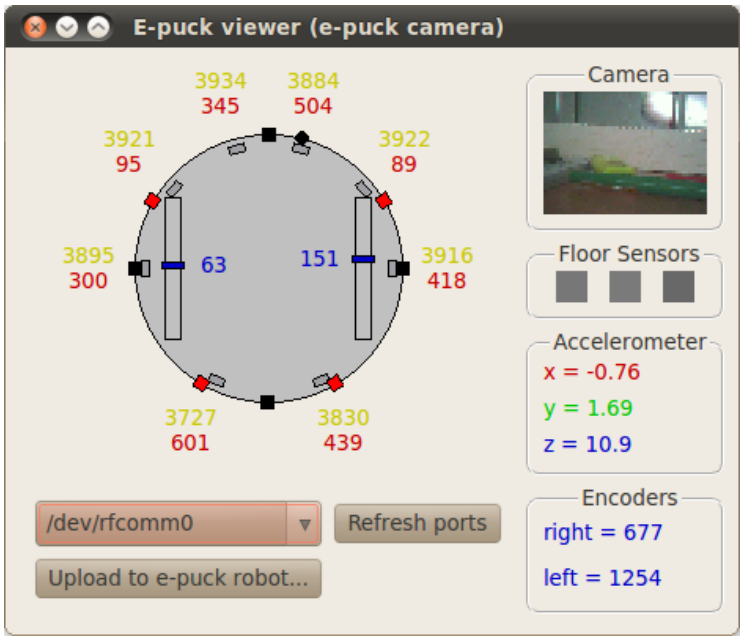


Figure 8.6: The e-puck control window for simulation

distance measurements. The 10 LEDs are displayed in black when off and red (or green) when on. The motor speeds are displayed in blue, and the motor position is displayed in the Encoder box in the bottom right hand corner of the window. The camera image (if present), the ground sensor values (if present) and the accelerometer values are displayed in the corresponding boxes on the right side of the window.

This e-puck control window appears because the `robotWindow` field of the `Differential-Wheel` node in the world file was set to "e-puck_window". Changing this `robotWindow` to an empty string will disable this control window.

BotStudio

BotStudio is a user interface for programming graphically the e-puck thanks to a finite state automaton. Behaviors such as wall follower, collision avoider or line follower can be implemented quickly thanks to this interface. BotStudio is typically destinated for the education field, particularly for beginners in robotics.

An automaton state of BotStudio corresponds to a state of the e-puck actuators while a transition corresponds to a condition over its sensor values. A transition is fired when all of its conditions are fulfilled (logical AND). A logical OR can be performed by several transitions between two states.

The actuators available in BotStudio are the LEDs and the motors. Each automaton state have two sliders for setting the motor speed value. Note that these values can be unset by clicking on the cursor of the slider. Each state have also 10 square buttons for setting the LEDs states. A red button means the LED is turned on, a black one means it is turned off and a grey one means there is no modification.

The sensor available in BotStudio are the distance sensors and the camera. Moreover a timer can be used to temporize the conditions by dragging the corresponding slider. Conditions over the IR sensors can be set by dragging the 8 red sliders. A condition can be reversed by clicking on the grey part of the slider. Finally, the camera is used for giving a clue on the front environment of the e-puck. An algorithm is applied on the last line of the camera and returns a integer between -10 and 10 indicating if a black line is perceived respectively at the left and at the right of the e-puck field of view. A condition can be set on this value for getting a line follower behavior.

BotStudio is depicted in the figure 8.7. An example of BotStudio can be found by opening the `WEBOTS_MODULES_PATH/projects/robots/e-puck/world/e-puck_botstudio.wbt` world file.

The BotStudio windows appears when the e-puck's controller points on a *.bsg* file.

Bluetooth setup

The e-puck has a Bluetooth interface allowing it to communicate with Webots. This feature is available under Windows, Linux and Mac OS X. The Bluetooth interface must be set up accord-

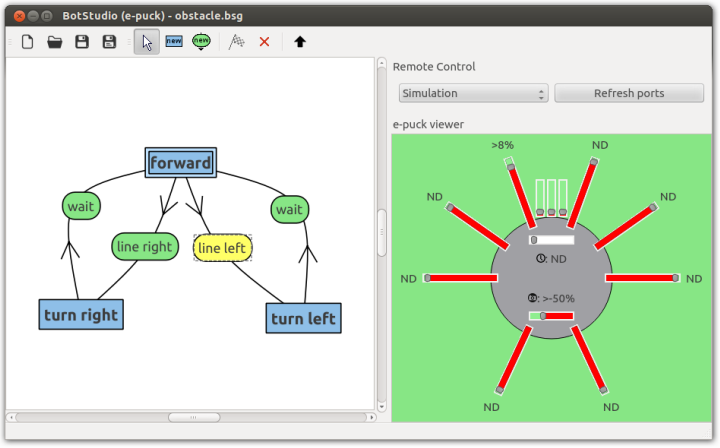


Figure 8.7: BotStudio

ing to your operating system (OS). Generally it is as simple as using the Bluetooth interface of your OS in order to discover and to pair the e-puck as a regular Bluetooth device. The complete instructions about pairing can be found on the GCTronic website[5].

On linux, the pairing has to be done manually (without using the Bluetooth interface of the OS). This can be done by using the `rfcomm` command. Once generated, the rfcomm file has to be given to Webots through an environment variable. It may also occur that the rfcomm file doesn't have the read rights. A typical pairing can be done using the following commands:

```
# Get the e-puck MAC adress
$ hcitool scan
Scanning ...
        10:00:E8:52:BF:32       e-puck_1368
# Bind the MAC adress of the e-puck with a non-existing rfcomm file
sudo rfcomm bind /dev/rfcomm1 10:00:E8:52:BF:32
# (Optional) Grant the read rights to the rfcomm file
sudo chmod 666 /dev/rfcomm1
# Export the WEBOTS_COM? environment variable (with ? between 1 to 9)
export WEBOTS_COM1=/dev/rfcomm1
# Launch Webots
webots
```

Bluetooth remote control

Once properly set up, your Bluetooth connection to your e-puck should appear in the popup menu of the control. If it doesn't appear there, it means that your computer was not properly

[5] http://www.gctronic.com/doc/index.php/E-Puck#Getting_started

configured to interface with your e-puck robot through Bluetooth. Please refer to the instructions given in the previous section.

When selecting a specific Bluetooth connection from the popup menu of the control window, Webots will try to establish a connection with your e-puck robot. Once connected, it will display the version of the e-puck serial communication software on the Webots console (e.g. 'Running real e-puck (Version 1.4.3 March 2010 (Webots))'), and will switch the control to the real robot. That is, it will send motor commands to the real robot and display sensor information (proximity, light, camera image, etc.) coming from the real robot. This makes the transfer from the simulation to the real robot trivially simple. Note that in the same popup menu, the **Refresh ports** menu item can be used for updating the COM ports.

The remote control has two requirements: the Bluetooth must be correctly set up (computer side) and the e-puck must be programmed with the Webots last firmware. For setting up Bluetooth, please refer to the official e-puck website. For uploading the last firmware on your robot, switch on your robot, press the **Upload to e-puck robot...** button on the control window and finally select the select the COM port which corresponds to your robot and the `WEBOTS_MODULES_PATH/projects/robots/e-puck/transfer/firmware/firmware-x.x.x.hex` file located in your Webots directory (*x.x.x* has to be replaced by the current firmware's version).

Cross-compilation

An alternative to the remote-control session for running the real e-puck is to cross-compile your code and to upload it on the e-puck.

For using this feature, your code has to be written in C and to use the C Webots API. Moreover, you need to define a specific Makefile called `Makefile.e-puck` in the controller directory. This Makefile must include the following file:

```
include $(WEBOTS_MODULES_PATH)/projects/robots/e-puck/transfer/
   libepuck/Makefile.include
```

Thanks to this, it is possible to cross-compile with Webots by using the **Build** > **Cross-compile** menu item of the text editor. Note that the **Upload to e-puck robot...** button of the e-puck control window allows you to upload a file generated by the cross-compilation extended by `.hex` on the e-puck robot.

An example of cross-compilation is given in the `WEBOTS_MODULES_PATH/projects/robots/e-puck/controllers/e-puck_cross-compilation` subdirectory of your Webots directory.

Cross-compilation issues on Linux 64 bit

When cross-compiling on Linux 64 bit, it may occur such kind of error:

```
/bin/sh: 1:
pic30-elf-gcc: not found
make: *** [e-puck_cross-compilation-pic30.o] Error 127
```

This error can be fixed simply by installing the following packets from a terminal:

```
sudo apt-get install gcc-4.6-base:i386 libgcc1:i386 libc6:i386
```

8.2 Using the Nao robot

8.2.1 Introduction

The Nao robot is a humanoid robot developed by Aldebaran Robotics[6]. This section explains how to use Nao robot simulated in Webots together with the Choregraphe program of Aldebaran Robotics[7]. Currently Webots supports the Nao v3.3, v4.0 and v5.0 versions, with and without their articulated fingers (respectively with 25 and 21 degrees of freedom) for the first two.

The Webots installation includes several world files with Nao robots. You will find some in this folder: `WEBOTS_MODULES_PATH/projects/robots/aldebaran/worlds`. The `nao.wbt` and `nao_indoors.wbt` are meant to be used with Choregraphe (see below). The `nao_demo.wbt` is a demonstration of a very simple controller that uses Webots C API instead of Choregraphe. The `nao_matlab.wbt` world is an example of programming Webots using the Matlab API. The `nao_robocup.wbt` world is an example of how to use the NAOqi API inside Webots. It is the same API that is used in Choregraphe, meaning that you can program Nao inside Webots without using Choregraphe if you want to. In this world, Nao tries to shoot the ball in the goal. You can find another NAOqi example in the `WEBOTS_MODULES_PATH/projects/contests/nao_challenge/2013-2014/worlds` folder. The `challenge.wbt` file in this folder is a solution to the NAO Challenge contest (edition 2013-2014).

In addition Nao robots are also used in the world files of the Robotstadium[8] contest. These files are located in this folder: `WEBOTS_MODULES_PATH/projects/contests/robotstadium/worlds`.

8.2.2 Using Webots with Choregraphe

These instructions have been tested with Webots 8.0.0 and Choregraphe 2.1.1.10. Please note that Webots must not be launched as root when using any world containing naoqisim, otherwise Choregraphe won't be able to send instructions to the robot in Webots.

[6] `http://www.aldebaran-robotics.com`
[7] `http://www.aldebaran-robotics.com`
[8] `http://www.robotstadium.org`

Start Webots and open this world file: `WEBOTS_MODULES_PATH/projects/robots/aldebaran/worlds/nao.wbt` You should see a red Nao in an empty environment. If the simulation is paused, then please start it by pushing the **Real-time** button in Webots.

The camera images in Webots (small purple viewports) should reflect what the robot sees.

Several lines of text information corresponding to the output of NAOqi should be printed to Webots console.

Now you can start Choregraphe with the –no-naoqi option. Please make sure the Choregraphe version matches the NAOqi version printed in Webots console. In Choregraphe choose the menu **Connection** > **Connect to...**. Then in the list, select the NAOqi that was started by Webots, on you local machine, it will have the port number 9559, unless you change it. Note that the NAOqi will not appear in the list if the simulation was not started in Webots. If the simulation was started but the robot still doesn't appear in the list, force the IP and port to 127.0.0.1 and 9559 in Choregraphe and then press connect.

At this point a Nao model matching the Webots model should appear in Choregraphe. Now, in Choregraphe toggle the "Wake up" button, which is a little sun in the rop right of the window. Nao is currently in the "Stand Zero" pose, you can change its starting pose using the posture library in Choregraphe.

Then double-click on any of the Nao parts in Choregraphe: a small window with control sliders appears. Now, move any of the sliders: the motor movement in Choregraphe should be reflected in the Webots simulation. If you open the Video monitor in Choregraphe you should see the picture of the Nao camera simulated by Webots.

8.2.3 Nao models

You can switch between the Nao model thanks to the following Nao PROTO fields:

- *version* corresponds to the real Nao version. The supported versions are "3.3", "4.0" and "5.0". The main difference between these models is the different calibration of the physics. The field of view of the cameras is slightly different, too. Please refer directly to the Nao.proto file to see the complete difference. Note that each version having a different weight repartition in their body, the best contact properties in the simulated world aren't always the same. They are currently optimized for the version 5.0 of Nao in the default Nao worlds and may not perform as well with previous versions of Nao.
-

8.2.4 Using motion boxes

Now we can test some of the motion boxes of Choregraphe. A simple example is a sit down -> stand up motion. In Choregraphe, select the "Sit Down" and "Stand Up" boxes from **Box libraries**

> **default**. Drag and drop them in central view. Then connect the global "onStart" input to the "Sit Down" box's "onStart" input, and the output of this box to the "Stand Up" box's "onStart" input. Now make sure the simulation is running, and, push the **Play** button in Choregraphe. This will make the robot sit down, and then stand up once he is done sitting down.

8.2.5 Using the cameras

Webots simulates Nao's top and bottom cameras. Using Aldebaran's Choregraphe or the Monitor programs, it is possible to switch between these cameras. In Choregraphe, use the "Select Camera" box in **Box Library** > **Vision**. The simulated camera image can be viewed in Choregraphe: **View** > **Video monitor**. The resolution of the image capture can be changed in Webots using the `cameraWidth` and `cameraHeight` fields of the robot. Note that the simulation speed decreases as the resolution increases. It is possible to hide the camera viewports (purple frame) in Webots, by setting the `cameraPixelSize` field to 0. It is also possible to completely switch off the simulation of the cameras by adding the "-nocam" option before the NAOqi port number in the `controllerArgs` field, e.g. "-nocam 9559".

8.2.6 Using Several Nao robots

It is possible to have several Nao robots in your simulation, however each Nao robot must use a different NAOqi port. Here how to copy a Nao and assign the NAOqi port number:

1. Pause the simulation: push the **Pause** button in Webots 3D View
2. Revert the simulation: push the **Revert** button in Webots 3D View
3. In Webots Scene Tree, select a top level nodes, e.g. the Nao robot
4. Then push the **Add** button, a dialog appears
5. In the dialog, select `PROTO (Webots) > robots`
6. Then select one of the Nao models from the list, the Nao is added to the current world
7. Select the Nao in the 3D view and move it away from the other one: SHIFT + left mouse button
8. Select the `controllerArgs` field in the newly created robot and increase the port number, e.g. 9560
9. Save the .wbt file: push the **Save** button
10. Now you can push the **Real-time** button to run the simulation with several robots

Repeat the above procedure for each additional robot that you need. Remember that every robot must have a different port number specified in `controllerArgs`.

8.2.7 Getting the right speed for realistic simulation

Choregraphe uses exclusively real-time and so the robot's motions are meant to be carried out in real-time. The Webots simulator uses a virtual time base that can be faster or slower than real-time, depending on the CPU and GPU power of the host computer. If the CPU and GPU are powerful enough, Webots can keep up with real-time, in this case the speed indicator in Webots shows approximately 1.0x, otherwise the speed indicator goes below 1.0x. Choregraphe motions will play accurately only if Webots simulation speed is around 1.0x. When Webots simulation speed drifts away from 1.0x, the physics simulation gets wrong (unnatural) and thus Choregraphe motions don't work as expected any more. For example if Webots indicates 0.5x, this means that it is only able to simulate at half real-time the motion provided by Choregraphe: the physics simulation is too slow. Therefore it is important to keep the simulation speed as much as possible close to 1.0x. There are currently no means of synchronizing Webots and Choregraphe, but this problem will be addressed in a future release. It is often possible to prevent the simulation speed from going below 1.0x, by keeping the CPU and GPU load as low as possible. There are several ways to do that, here are the most effective ones:

- Switch off the simulation of the Nao cameras with the "-nocam" option, as mentioned above
- Increase the value of `WorldInfo.displayRefesh` in the Scene Tree
- Switch off the rendering of the shadows: change to FALSE the `castShadows` field of each light source in the Scene Tree
- Reduce the dimensions of the 3D view in Webots, by manually resizing the GUI components
- Remove unnecessary objects from the simulation, in particular objects with physics

8.2.8 Known Problems

If for some unexpected reason Webots crashes, it is possible that the `hal` or `naoqi-bin` processes remain active in memory. In this case we recommend you to terminate these processes manually before restarting Webots.

On Windows, use the Task Manager (the Task Manager can be started by pressing Ctrl-Alt-Delete): In the Task Manager select the **Processes** tab, then select each `hal.exe` and `naoqi-bin.exe` line and push the "End Process" button for each one.

On Linux, you can use the `killall` or the `pkill` commands, e.g.:

```
$ killall hal naoqi-bin
```

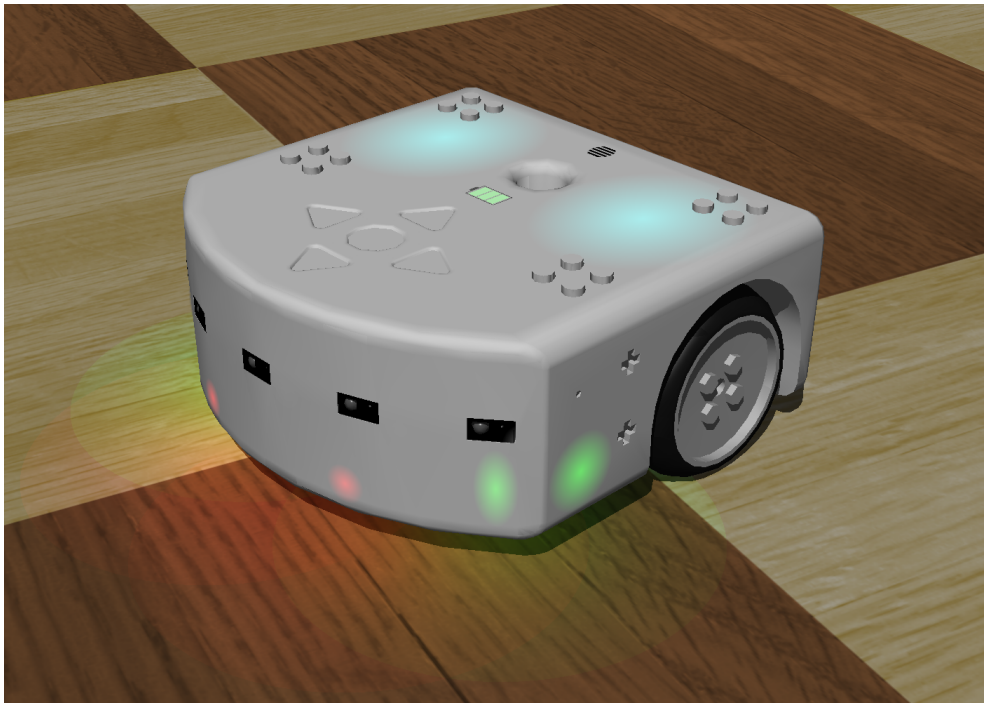


Figure 8.8: Thymio II model in Webots

8.3 Using the Thymio II robot

Thymio II is an affordable educational robot. It provides three main features: a large number of sensors and actuators, an educative interactivity based on light and touch, a programming environment featuring graphical and text programming.

More information about the Thymio II is available from its official website[9].

Webots contains an accurate model of the Thymio II robot (see the figure 8.8). Almost all the Thymio II devices have been modeled and calibrated. Moreover Aseba studio and VPL for Thymio II can be connected on the simulated model allowing you to program the simulated robot using Aseba. Many Aseba examples are working directly with the simulated robot. Finally several objects related to the Thymio II are available, including a pen which can draw on any 3D object.

8.3.1 Thymio II model

The table 8.5 shows which devices are supported by the model, and their names (using the Webots terminology).

[9] `https://aseba.wikidot.com/en:thymio`

Device	Support	Webots name
Motors	Full support	motor.[left-right]
RGB LEDs	Full support	leds.top, leds.bottom.[right-left]
LEDs	Full support	leds.buttons.led[0-3], leds.circle.led[0-7], leds.prox.h.led[0-7], leds.prox.v.led[0-1], leds.sound, leds.rc, leds.temperature.[red-blue]
IR sensors	Full support	prox.horizontal.[0-6], prox.ground.[0-1]
Accelerometer	Full support	acc
Buttons	Full support	button.[forward-backward-left-right-center]
Microphone	Clap event only	through the robot window
Speaker	Not supported	N/A
Temperature sensor	Not supported	N/A
RC device	Not supported	N/A

Table 8.5: Thymio II devices

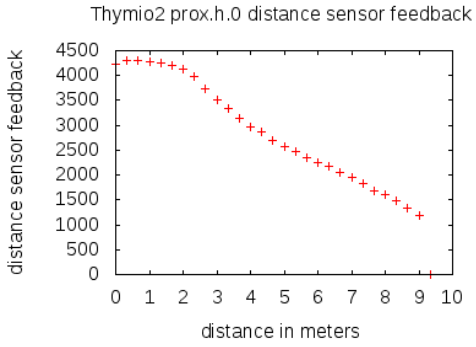


Figure 8.9: Proximity sensor response versus distance

The Thymio II distance sensor feedback is given on figure 8.9. The calibration was performed using a regular A4 white paper.

8.3.2 Connect Aseba to the Thymio II model

The default controller of the Thymio II PROTO is the `thymio2_demo` controller. It should be changed to `thymio2_aseba` to allow the connection to Aseba programming environment. However, most world files including the Thymio II robot are already configured to use `thymio2_aseba` as a controller for the Thymio II robot. Technically, `thymio2_aseba` creates a TCP/IP server on which Aseba can be connected, and it wraps the Aseba API with the Webots API.

Here is how to proceed to connect Aseba to the Thymio II model in Webots. Make sure that the simulation is running (the controller has started) and that the controller of the Thymio II

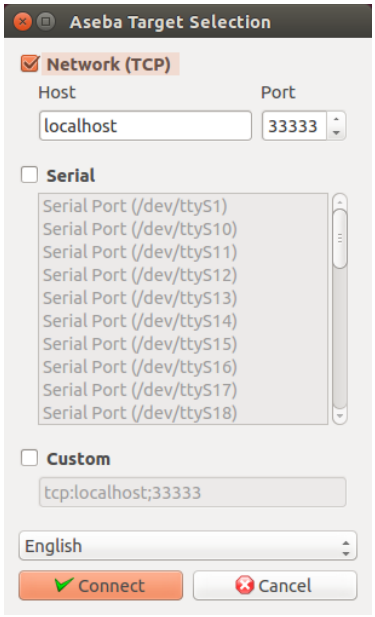


Figure 8.10: Aseba Studio and VPL target selection dialog

robot is `thymio2_aseba`. You can check this from the Webots scene tree, by opening the Thymio2 node. Aseba Studio or VPL for Thymio II can then be started. From the Aseba target selection dialog (see the figure 8.10.), select the `Network TCP/IP` option with the following parameters: `Host = localhost` and `Port = 33333`. Then just click on the `Connect` button.

In case of a simulation containing several Thymio II, the TCP/IP port of the `thymio2_aseba` controller should be unique for each robot instance. This value can be modified by editing the `Thymio2::controllerArgs` field.

The Thymio II window (see the figure 8.11) can help you to raise some events easily. These events are mainly useful when using the VPL for Thymio II software. To open the Thymio II window, just double click on the 3D model of the robot.

8.3.3 Thymio II Pen

You can easily add a pen in the simulated model by adding a `Thymio2Pen` node to the `Thymio2::bodySlot` field. This pen can draw on every 3D object. This is particularly useful to perform these exercises[10]. An example of this is located there (see the figure 8.12): `WEBOTS_MODULES_PATH/projects/robots/thymio/worlds/thymio2_pen.wbt`

[10] `https://aseba.wikidot.com/en:thymiodrawing`

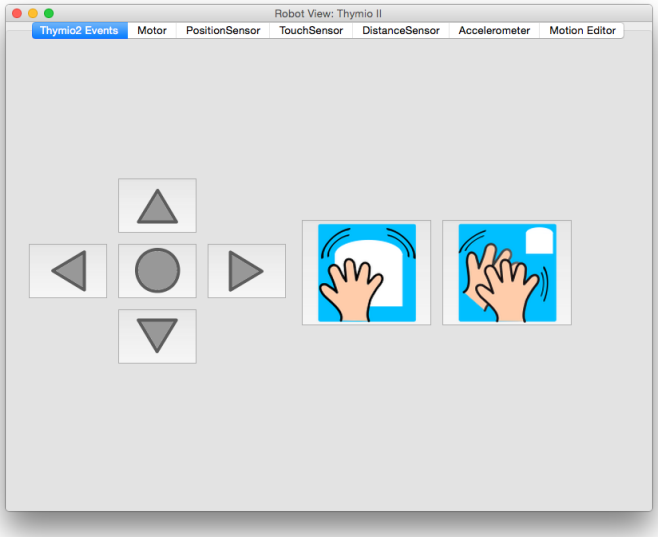


Figure 8.11: Thymio II robot window

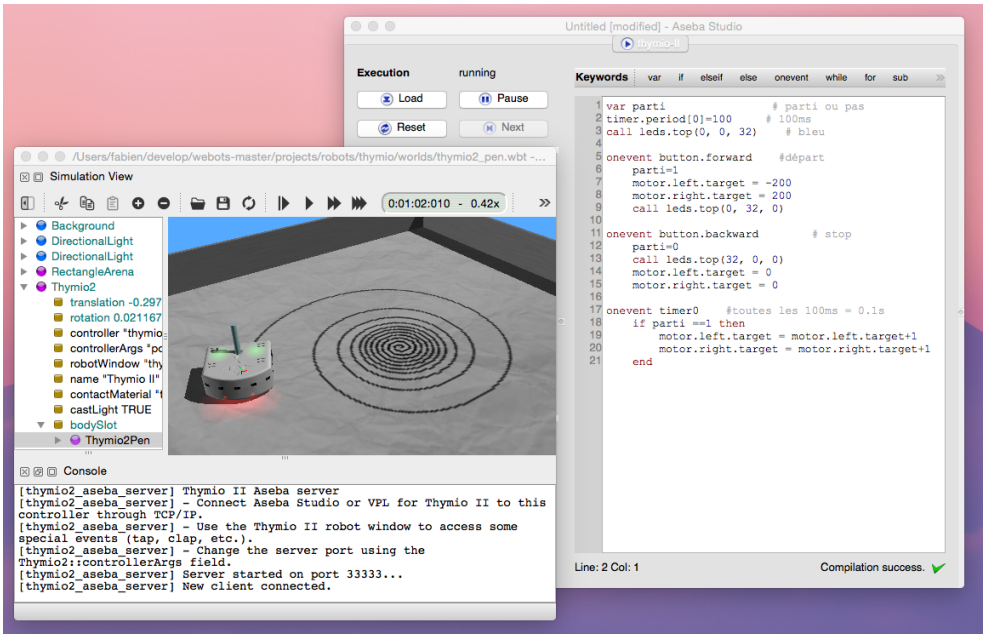


Figure 8.12: Simulation of a Thymio II having a pen.

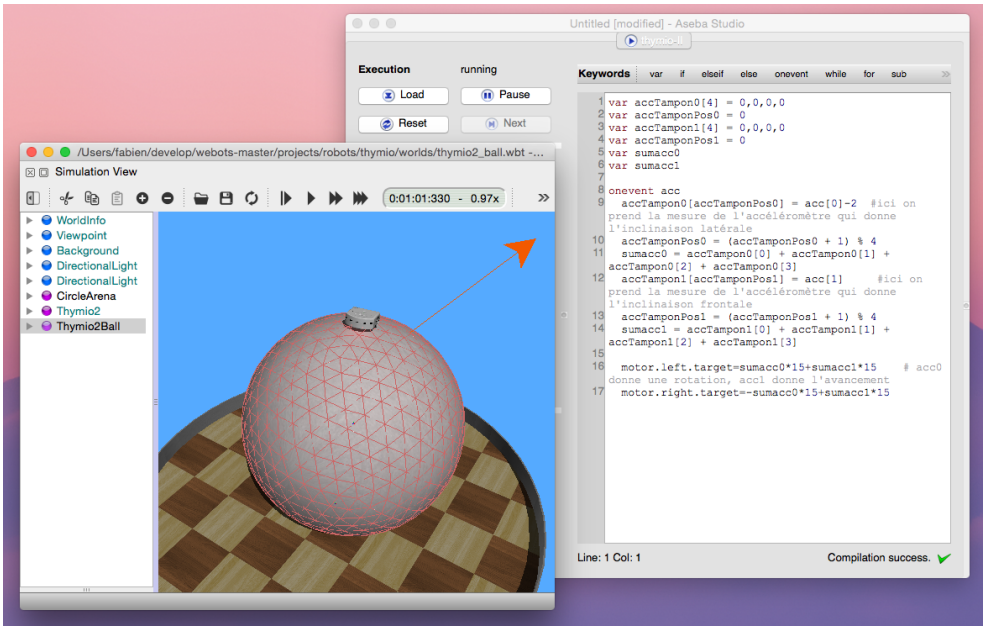


Figure 8.13: Simulation of a Thymio II above a ball.

8.3.4 Thymio II Ball

These exercises[11] can be reproduced by adding a `Thymio2Ball` node in your world. The ball can be slightly moved by applying a force on it (`ALT + mouse left click`). An example of this is located there (see the figure 8.13): `WEBOTS_MODULES_PATH/projects/robots/thymio/worlds/thymio2_ball.wbt`

8.4 Using the Pioneer 3-AT and Pioneer 3-DX robots

8.4.1 Pioneer 3-AT

In this section, you will learn how to use Webots simulation model of the Pioneer 3-AT robot. (figure 8.14).

Overview of the robot

The Pioneer 3-AT robot is an all-purpose outdoor base, used for research and prototyping applications involving mapping, navigation, monitoring, reconnaissance and other behaviors. It provides a ready-to-use set of devices listed in table 8.6.

[11] `https://aseba.wikidot.com/en:thymioballeinverse`

Figure 8.14: Pioneer 3-AT, a ready-to-use all terrain base

Feature	Description
Dimensions	508 mm long, 497 mm large, 277 mm high
Weight	12 kg, operating playload of 12 kg on floor
Batteries	2-4 hours, up to 3 lead acid batteries of 7.2 Ah each, 12 V
Microcontroller I/O	32 digital inputs, 8 digital outputs, 8 analog inputs, 3 serial extension ports
Skid steering drive	Turn radius: 0 cm, swing radius: 34 cm, max. traversable grade: 35%
Speed	Max. forward/backward speed: 0.7 m/s; Rotation speed: 140 deg/s

Table 8.6: Pioneer 3-AT features

More information on the specifications and optional devices is available on Adept Mobile Robots official webpage[12].

Simulation model

The Pioneer 3-AT model in Webots is depicted in figure 8.15. This model includes support for 4 motors and 16 sonar sensors (8 forward-facing, 8 rear-facing) for proximity measurements. The standard model of the Pioneer 3-AT is provided in the `pioneer3AT.wbt` file which is located in the `WEBOTS_MODULES_PATH/projects/robots/pioneer/pioneer3at/worlds` directory of the Webots distribution.

The `pioneer3at.wbt` world file is a simulation example of a simple obstacle avoidance behavior based on the use of a SICK LIDAR (see the `obstacle_avoidance_with_lidar.c` controller file in the `WEBOTS_MODULES_PATH/projects/robots/pioneer/pioneer3at/controller` directory).

[12] `http://www.mobilerobots.com/ResearchRobots/ResearchRobots/P3AT.aspx`

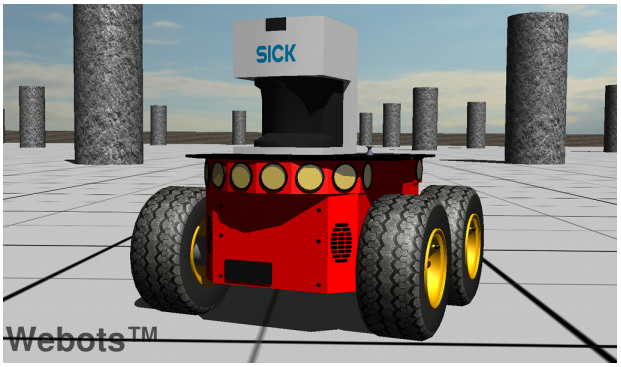


Figure 8.15: The Pioneer 3-AT model in Webots

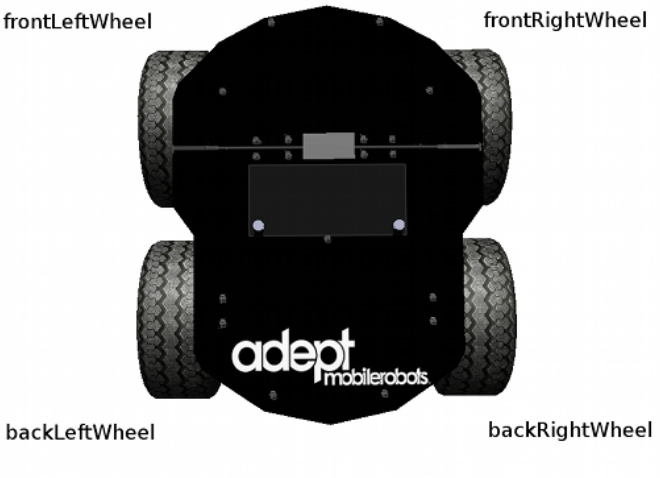


Figure 8.16: Pioneer 3-AT motor names

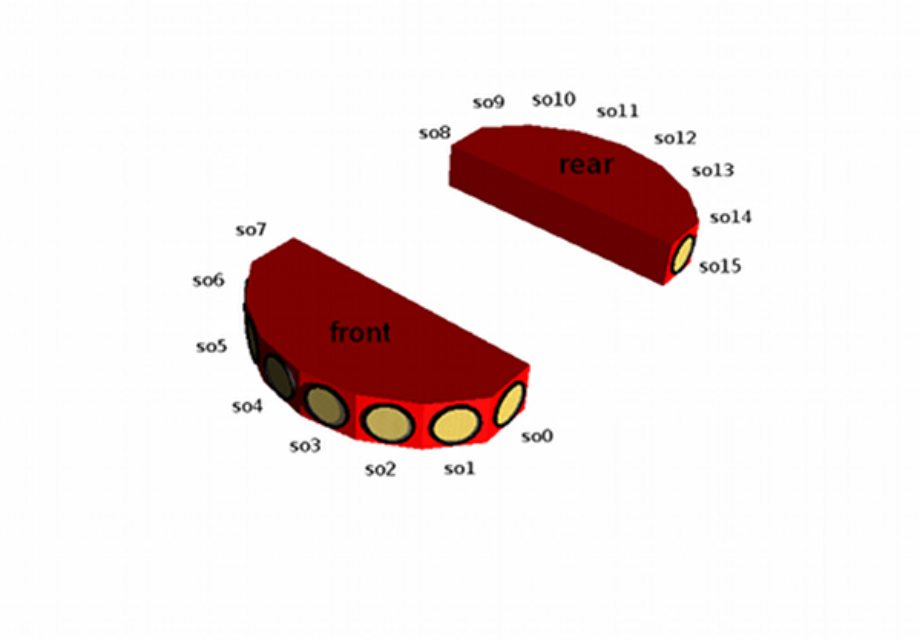


Figure 8.17: Sonar sensors positions

The Pioneer 3-AT motors are RotationalMotor nodes named according to figure 8.16. The `wb_set_motor_position()` and `wb_set_motor_velocity()` functions allow the user to manage the rotation of the wheels. The sonar sensors are numbered according to figure 8.17.

The angle between two consecutive sensor directions is 20 degrees except for the four side sensors (so0, so7, so8 and so15) for which the angle is 40 degrees.

8.4.2 Pioneer 3-DX

In this section, you will learn how to use Webots simulation model of the Pioneer 3-DX robot. (figure 8.18).

Overview of the robot

The base Pioneer 3-DX platform is assembled with motors featuring 500-tick encoders, 19 cm wheels, tough aluminum body, 8 forward-facing ultrasonic (sonar) sensors, 8 optional real-facing sonar, 1, 2 or 3 hot-swappable batteries, and a complete software development kit. The base Pioneer 3-DX platform can reach speeds of 1.6 meters per second and carry a payload of up to 23 kg.

The Pioneer 3-DX robot is an all-purpose base, used for research and applications involving mapping, teleoperation, localization, monitoring, reconnaissance and other behaviors. Pioneer 3-DX is provided with a ready-to-use set of devices listed in table 8.7.

Figure 8.18: Pioneer 3-DX, an all-purpose base, used for research and applications

Feature	Description
Dimensions	455 mm long, 381 mm large, 237 mm high
Weight	9 kg, operating playload of 17 kg
Batteries	8-10 hours, 3 lead acid batteries of 7.2 Ah each, 12 V
Microcontroller I/O	32 digital inputs, 8 digital outputs, 8 analog inputs, 3 serial extension ports
Skid steering drive	Turn radius: 0 cm, swing radius: 26.7 cm, max. traversable grade: 25%
Speed	Max. forward/backward speed: 1.2 m/s; Rotation speed: 300 deg/s

Table 8.7: Pioneer 3-AT features

More information on the specifications and optional devices is available on Adept Mobile Robots official webpage[13].

Simulation model

The Pioneer 3-DX model in Webots is depicted in figure 8.19. This model includes support for two motors, the caster wheel, 7 LEDs on the control panel and 16 sonar sensors (8 forward-facing, 8 rear-facing) for proximity measurements. The standard model of the Pioneer 3-DX is provided in the `pioneer3dx.wbt` file which is located in the `WEBOTS_MODULES_PATH/projects/robots/pioneer/pioneer3dx/worlds` directory of the Webots distribution.

The `pioneer3dx.wbt` world file shows a simulation example of the Braitenberg avoidance algorithm based on the use of the 16 sonar sensors (see the `braitenberg.c` controller file in the `WEBOTS_MODULES_PATH/projects/robots/pioneer/pioneer3dx/controller`

[13] `http://www.mobilerobots.com/ResearchRobots/PioneerP3DX.aspx`

Figure 8.19: The Pioneer 3-DX model in Webots

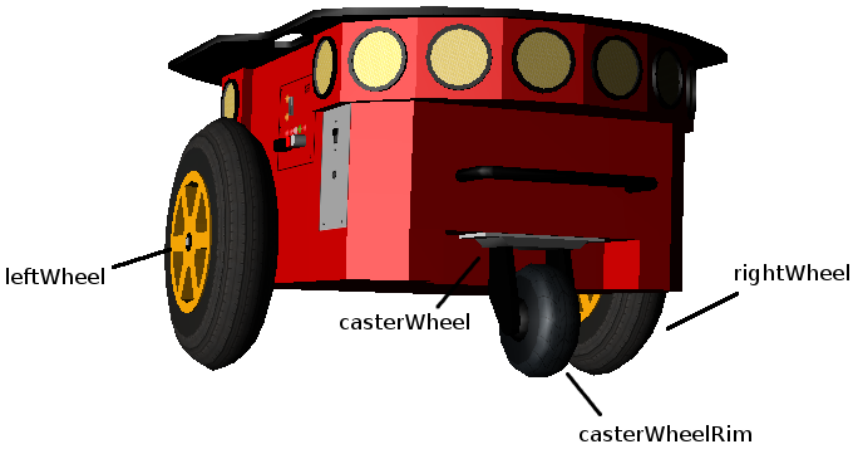


Figure 8.20: Pioneer 3-DX motor names

directory). The `pioneer3dx_with_kinect.wbt` world file in the same directory is a simple simulation example of an obstacle avoidance behaviour based on a Microsoft kinect sensor (see the `obstacle_avoidance_kinect.c` controller file).

The Pioneer 3-DX motors are RotationalMotor nodes named according to figure 8.20. The `wb_set_motor_position()` and `wb_set_motor_velocity()` functions allow the user to manage the rotation of the wheels. The sonar sensors are numbered according to figure 8.17.

The angle between two consecutive sensor directions is 20 degrees except for the four side sensors (so0, so7, so8 and so15) for which the angle is 40 degrees.

Chapter 9

Webots FAQ

This chapter is a selection of frequently asked questions found on the Webots forum[1]. You may find additional information directly in the group. Other useful sources of information about Webots include: Webots Reference Manual[2] and Cyberbotics' Robot Curriculum[3].

9.1 General FAQ

9.1.1 What are the differences between Webots PRO, Webots EDU and other Webots modules?

Webots PRO provides a fully featured version of Webots intended for robotics research. Webots EDU provides a special version of Webots well suited for education. Webots modules are components tailored for specific uses of Webots, they include different models of robots, objects, environments, programming interfaces, libraries, etc. Users can purchase only the modules they need separately. The differences between Webots modules are explained here[4].

9.1.2 How can I report a bug in Webots?

If you can still start Webots, please report the bug by using Webots menu: **Help** > **Bug report...**.

If Webots cannot start any more, please report the bug there: http://www.cyberbotics.com/bug[5]. Please include a precise description of the problem, the sequence of actions necessary to reproduce the problem. Do also attach the world file and the controller programs necessary to reproduce it.

[1] http://www.cyberbotics.com/forum
[2] http://www.cyberbotics.com/reference/
[3] http://en.wikibooks.org/wiki/Cyberbotics'_Robot_Curriculum
[4] http://www.cyberbotics.com/webots/
[5] http://www.cyberbotics.com/bug

Before reporting a bug, please make sure that the problem is actually caused by Webots and not by your controller program. For example, a crash of the controller process usually indicates a bug in the controller code, not in Webots. This situation can be identified with these two symptoms:

1. Webots GUI is visible and responsive, but the simulation is blocked (simulation time stopped).
2. The controller process has vanished from the *Task Manager* (Windows) or is shows as <*defunct*> when using `ps -e` (Linux/Mac).

9.1.3 Is it possible to use Visual C++ to compile my controllers?

Yes. However, you will need to create your own project with all the necessary options. You will find more detailed instructions on how to do that in section 5.6. To create the import libraries (the `*.lib` files in Visual C++) from the `*.dll` files of the lib directory of Webots, please follow the instructions provided with the documentation of your compiler.

9.2 Programming

9.2.1 How can I get the 3D position of a robot/object?

There are different functions depending whether this information must be accessed in the controller, in the Supervisor or in the physics plugin. Note that Webots PRO is required for using `Supervisor` and the physics plugin functions. All the functions described below will return the 3D position in meters and expressed in the global (world) coordinate system.

Clearly, the position of a robot can also be approximated by using *odometry* or *SLAM* techniques. This is usually more realistic because most robots don't have a GPS and therefore have no mean of precisely determining their position. You will find more info about *odometry* and *SLAM* techniques in Cyberbotics' Robot Curriculum.

In controller code:

To get the position of a robot in the robot's controller code: add a `GPS` node to the robot, then use `wb_robot_get_device()`, `wb_gps_enable()` and `wb_gps_get_values()` functions. Note that the `GPS`'s resolution field must be 0 (the default), otherwise the results will be noisy. You will find more info about the `GPS` node and functions in Reference Manual[6]. Note that the `GPS` can also be placed on a robot's part (arm, foot, etc.) to get the world/global coordinates of that particular part.

[6] `http://www.cyberbotics.com/reference/`

In Supervisor code:

1. To get the 3D position of any `Transform` (or derived) node in the `Supervisor` code: you can use the `wb_supervisor_node_get_position()` function. Please check this function's description in the Reference Manual.

2. To get the 3D position of any `Transform` (or derived) node placed at the root of the Scene Tree (the nodes visible when the Scene Tree is completely collapsed), you can use the `wb_supervisor_field_get_sf_vec3f()` function. Here is an `example`.

A simulation example that shows both the `GPS` and the `Supervisor` techniques is included in the Webots installation, you just need to open this world: `WEBOTS_MODULES_PATH/projects/samples/devices/worlds/gps.wbt`.

In physics plugin code:

In the physics plugin you can use ODE's `dBodyGetPosition()` function. Note that this function returns the position of the center of mass of the body: this may be different from the center of the `Solid`. Please find a description of ODE functions here[7].

9.2.2 How can I get the linear/angular speed/velocity of a robot/object?

Webots provides several functions to get the 3D position of a robot or an object (see above): by taking the first derivative of the position you can determine the velocity. There are also some functions (see below) that can be used to get the velocity directly:

In controller code:

To get the angular velocity of a robot (or robot part) in the robot's controller code: add a `Gyro` node to the robot (or robot part), then use `wb_robot_get_device()`, `wb_gyro_enable()` and `wb_gyro_get_values()` functions. You will find more information about the `Gyro` node and functions in the Reference Manual.

Using a Supervisor:

Using the `wb_supervisor_node_get_velocity()` function it is possible to retrieve both the linear and angular velocity of any `Solid` node. You will find more information about this function in the Reference Manual.

[7] `http://ode-wiki.org/wiki/index.php?title=Manual`

In physics plugin code:

In the physics plugin you can use ODE's `dBodyGetLinearVel()` and `dBodyAngularVel()` functions. These functions return the linear velocity in meters per second, respectively the angular velocity in radians per second. Please find a description of ODE functions here: here[8].

9.2.3 How can I reset my robot?

Please see subsection 6.3.2.

9.2.4 What does this mean: "Could not find controller {...} Loading void controller instead." ?

This message means that Webots could neither find an executable file (e.g. .exe), nor an interpreted language file (e.g. .class, .py, .m) to run as controller program for a robot. In fact, Webots needs each controller file to be stored at specific location in order to be able to executed it. The requested location is in the `controllers` subdirectory of the current Webots project directory, e.g. `my_project`. Inside the `controllers` directory, each controller project must be stored in its own directory which must be named precisely like the `controller` field of the Robot. Inside that directory, the executable/interpretable file must also be named after the `controller` field of the Robot (plus a possible extension). For example if the controller field of the robot looks like this, in the Scene Tree:

```
Robot {
  controller "my_controller"
}
```

then the executable/interpretable file will be searched at the following paths:

```
my_project/controllers/my_controller/my_controller.exe (Windows only)
my_project/controllers/my_controller/my_controller (Linux/Mac only)
my_project/controllers/my_controller/my_controller.class
my_project/controllers/my_controller/my_controller.py
my_project/controllers/my_controller/my_controller.m
```

If Webots does not find any file at the above specified paths, then the error message in question is shown. So this problem often happens when you:

- Have moved the project or source files to a location that does not correspond to the above description.
- Use an external build system, e.g. Visual Studio, that is not configured to generate the executable file at the right location.

[8] `http://ode-wiki.org/wiki/index.php?title=Manual`

- Have changed the Robot's controller field to a location where no executable/interpretable file can be found.
- Have "reverted" the world after "cleaning" of the controller project.

9.2.5 What does this mean: "Warning: invalid WbDeviceTag in API function call" ?

A `WbDeviceTag` is an abstract reference (or handle) used to identify a simulated device in Webots. Any `WbDeviceTag` must be obtained from the `wb_robot_get_device()` function. Then, it is used to specify a device in various Webots function calls. Webots issues this warning when the `WbDeviceTag` passed to a Webots function appears not to correspond to a known device. This can happen mainly for three reasons:

1. The `WbDeviceTag` is 0 and thus invalid because it was not found by `wb_robot_get_device()`. Indeed, the `wb_robot_get_device()` function returns 0, if it cannot not find a device with the specified name in the robot. Note that the name specified in the argument of the `wb_robot_get_device()` function must correspond to the `name` field of the device, not to the VRML DEF name!
2. Your controller code is mixing up two types of `WbDeviceTag`s, for example because it uses the `WbDeviceTag` of a `Camera` in a `wb_distance_sensor_*()` function. Here is an example of what is wrong:

```
#include <webots/robot.h>
#include <webots/camera.h>
#include <webots/distance_sensor.h>

#define TIME_STEP 32

int main() {
  wb_robot_init();
  WbDeviceTag camera = wb_robot_get_device("camera");
  wb_camera_enable(camera, TIME_STEP);
  ...
  double value = wb_distance_sensor_get_value(camera);  // WRONG!
  ...
}
```

3. The `WbDeviceTag` may also be invalid because it is used before initialization with `wb_robot_get_device()`, or because it is not initialized at all, or because it is corrupted by a programming error in the controller code. Here is such an example:

```
#include <webots/robot.h>
#include <webots/camera.h>
```

```
#include <webots/distance_sensor.h>

#define TIME_STEP 32

int main() {
  wb_robot_init();
  WbDeviceTag distance_sensor, camera = wb_robot_get_device("
     camera");
  wb_camera_enable(camera, TIME_STEP);
  wb_distance_sensor_enable(distance_sensor, TIME_STEP);  //
     WRONG!
  ...
}
```

9.2.6 Is it possible to apply a (user specified) force to a robot?

Yes. You need to use a *physics plugin* to apply user specified forces (or torques). Note that Webots PRO is required to create a physics plugin. Then you can add the physics plugin with the menu item: **Wizards** > **New Physics Plugin**. After having added the plugin you must compile it using Webots editor. Then you must associate the plugin with your simulation world. This can be done by editing the `WorldInfo.physics` field in the Scene Tree. Then you must modify the plugin code such as to add the force. Here is an example:

```
#include <ode/ode.h>
#include <plugins/physics.h>

dBodyID body = NULL;

void webots_physics_init() {
  // find the body on which you want to apply a force
  body = dWebotsGetBodyFromDEF("MY_ROBOT");
  ...
}

void webots_physics_step() {
   ...
   dVector3 f;
   f[0] = ...
   f[1] = ...
   f[2] = ...
   ...
   // at every time step, add a force to the body
   dBodyAddForce(body, f[0], f[1], f[2]);
   ...
}
```

There is more info on the plugin functions in the Reference Manual in the chapter about Physics Plugins. Additional information about the ODE functions can be found here[9]. You may also want to study this example distributed with Webots:

`WEBOTS_MODULES_PATH/projects/samples/demos/worlds/salamander.wbt`

In this example, the physics plugin adds user computed forces to the robot body in order to simulate Archimedes and hydrodynamic drag forces.

9.2.7 How can I draw in the 3D window?

There are different techniques depending on what you want to draw:

1. If you just want to add some 2d text, you can do this by using the function: `wb_supervisor_set_label()`. This will allow you to put 2d overlay text in front of the 3d simulation. Please lookup for the `Supervisor` node in the Reference Manual.
2. If you want to add a small sub-window in front of the 3d graphics, you should consider using the `Display` node. This will allow you to do 2d vector graphics and text. This is also useful for example to display processed camera images. Please lookup for the `Display` node in the Reference Manual.
3. If you want add 3d graphics to the main window, this can be done by using a *physics plugin* (Webots PRO required). See how to add a physics plugin in the previous FAQ question, just above. After you have added the physics plugin you will have to implement the `webots_physics_draw` function. The implementation must be based on the OpenGL API, hence some OpenGL knowledge will be useful. You will find an sample implementation in the Reference Manual in the chapter about the Physics Plugin.

9.2.8 What does this mean: "The time step used by controller {...} is not a multiple of WorldInfo.basicTimeStep!"?

Webots allows to specify the *control step* and the *simulation step* independently. The control step is the argument passed to the `wb_robot_step()` function, it specifies the duration of a step of control of the robot. The *simulation step* is the value specified in `WorldInfo.basicTimeStep` field, it specifies the duration of a step of integration of the physics simulation, in other words: how often the objects motion must be recomputed. The execution of a simulation step is an atomic operation: it cannot be interrupted. Hence a sensor measurement or a motor actuation must take place between two simulation steps. For that reason the control step specified with each `wb_robot_step()` must be a multiple of the simulation step. If it is not the case you get this error message. So, for example if the `WorldInfo.basicTimeStep` is 16 (ms), then the control step argument passed to `wb_robot_step()` can be 16, 32, 48, 64, 80, 128, 1024, etc.

[9] `http://ode-wiki.org/wiki/index.php?title=Manual`

9.2.9 How can I detect collisions?

Webots does automatically detect collisions and apply the contact forces whenever necessary. The collision detection mechanism is based on the shapes specified in the `boundingObjects`. Now if you want to programmatically detect collision, there are several methods:

1. In controller code: you can detect collision by using `TouchSensors` placed around your robot body or where the collision is expected. You can use `TouchSensors` of type "bumper" that return a boolean status 1 or 0, whether there is a collision or not. In fact a "bumper" `TouchSensor` will return 1 when its `boundingObject` intersects another `boundingObject` and 0 otherwise.

2. In supervisor code (Webots PRO required): you can detect collisions by tracking the position of robots using the `wb_supervisor_field_get_*()` functions. Here is a naive example assuming that the robots are cylindrical and moving in the xz-plane.

```
#define ROBOT_RADIUS ...
...
int are_colliding(WbFieldRef trans1, WbFieldRef trans2) {
  const double *p1 = wb_supervisor_field_get_sf_vec3f(trans1);
  const double *p2 = wb_supervisor_field_get_sf_vec3f(trans2);
  double dx = p2[0] - p1[0];
  double dz = p2[2] - p1[2];
  double dz = p2[2] - p1[2];
  return sqrt(dx * dx + dz * dz) < 2.0 * ROBOT_RADIUS;
}
  ...
  // do this once only, in the initialization
  WbNodeRef robot1 = wb_supervisor_node_get_from_def("MY_ROBOT1")
     ;
  WbNodeRef robot2 = wb_supervisor_node_get_from_def("MY_ROBOT2")
     ;
  WbFieldRef trans1 = wb_supervisor_node_get_field(robot1, "
     translation");
  WbFieldRef trans2 = wb_supervisor_node_get_field(robot2, "
     translation");
  ...
  // detect collision
  if (are_colliding(trans1, trans2)) {
    ...
  }
```

3. In the physics plugin (Webots PRO required): you can replace or extend Webots collision detection mechanism. This is an advanced technique that requires knowledge of the

ODE (Open Dynamics Engine) API[10]. Your collision detection mechanism must be implemented in the `webots_physics_collide()` function. This function is described in the Physics Plugin chapter of the Reference Manual.

9.2.10 Why does my camera window stay black?

The content of the camera windows will appear only after all the following steps have been completed:

1. The `Camera`'s name field has been specified.
2. The `WbDeviceTag` for the `Camera` has been found with the function `wb_robot_get_device()`.
3. The `Camera` has been enabled using the function `wb_camera_enable()`.
4. The function `wb_camera_get_image()` (or `wb_camera_get_range_image()` for a "range-finder" `Camera`) has been called.
5. At least one `wb_robot_step()` (or equivalent function) has been called.

9.3 Modeling

9.3.1 My robot/simulation explodes, what should I do?

The explosion is usually caused by inappropriate values passed to the physics engine (ODE). There are many things you can be try to improve the stability of the simulation (adapted from ODE's User Guide):

1. Reduce the value of `WorldInfo.basicTimeStep`. This will also make the simulation slower, so a tradeoff has to be found. Note that the value of the control step (`wb_robot_step(TIME_STEP)`) may have to be adapted to avoid warnings.
2. Reduce the value of the `JointParameters.springConstant` and `JointParameters.dampingConstant` fields or avoid using springs and dampers at all.
3. Avoid large mass ratios. A `Joint` that connects a large and a small mass (`Physics.mass`) together will have a hard time to keep its error low. For example, using a `Joint` to connect a hand and a hair may be unstable if the hand/hair mass ratio is large.

[10] `http://ode-wiki.org/wiki/index.php?title=Manual`

4. Increase the value of `WorldInfo.CFM`. This will make the system more numerically robust and less susceptible to stability problems. This will also make the system look more *spongy* so a tradeoff has to be found.

5. Avoid making robots (or other objects) move faster than reasonably for the time step (`WorldInfo.basicTimeStep`). Since contact forces are computed and applied only at every time step, too fast moving bodies can penetrate each other in unrealistic ways.

6. Avoid building mechanical loops by using `Connector` nodes. The mechanical loops may cause constraints to fight each other and generate strange forces in the system that can swamp the normal forces. For example, an affected body might fly around as though it has life on its own, with complete disregard for gravity.

9.3.2 How to make replicable/deterministic simulations?

In order for a Webots simulation to be replicable, the following conditions must be fulfilled:

1. Each simulation must be restarted either by pushing the **Revert** button, or by using the `wb_supervisor_simulation_revert()` function, or by restarting Webots. Any other method for resetting the simulation will not reset the physics (velocity, inertia, etc.) and other simulation data, hence the simulation state will be reset only partly. The random seeds used by Webots internally are reset for each simulation restarted with one of the above methods.

2. The `synchronization` flag of every robot and supervisor must be TRUE. Otherwise the number of physics steps per control step may vary with the current CPU load and hence the robot's behavior may also vary.

3. The controllers (and physics plugin) code must also be deterministic. In particular that code must not use a pseudo random generator initialized with an non-deterministic seed such as the system time. For example this is not suitable for replicable experiments: `srand(time(NULL))`. Note that uninitialized variables may also be a source of un-determinstc behavior.

4. Each simulation must be executed with the same version of the Webots software and on the same OS platform. Different OS platforms and different Webots versions may result small numerical differences.

If the four above conditions are met, Webots simulations become replicable. This means that after the same number of steps two simulations will have exactly the same internal state. Hence if both simulation are saved using the **Save as...** button, the resulting files will be identical. This is true independently of the simulation mode used to execute the simulation: **Step**, **Real-Time**, **Run** or **Fast**. This is also true whether or not sensor noise is used (see below).

9.3.3 How to remove the noise from the simulation?

There are two sources of noise in Webots: the *sensor/actuator noise* and the *physics engine noise*. The amount of sensor/actuator noise can be changed (or removed) by the user (see below). The physics engine's noise cannot be changed because it is necessary for the realism of the simulation. To completely remove the sensor/actuator noise the following field values must be reset:

1. In the `lookupTables`: the third column of each `lookupTable` in the .wbt and .proto files must be reset to 0
2. In the `GPS` nodes: the `resolution` field must be reset to 0
3. In the `Camera` nodes: the `colorNoise` and the `rangeNoise` fields must be reset to 0
4. In the `DifferentialWheels` nodes: the value of `slipNoise` must be reset to 0 and the value of `encoderNoise` must be reset to -1

9.3.4 How can I create a passive joint?

First of all, any joint, passive or active, must be created by adding a `Joint`-derived node (depending on the constraint type requested) in the Scene Tree. A `Joint` is passive if its device is null (or at least not a `Motor`-derived node. Alternatively, it is also possible to make a `Motor` become passive during the simulation; this can be done like this:

```
wb_motor_set_motor_force(motor, 0.0);
```

The effect is similar to turning off the power of a real motor.

9.3.5 Is it possible fix/immobilize one part of a robot?

To immobilize one part of the robot, you need to fix the part to the static environment. This must be done with a *physics plugin* (Webots PRO required). You can add a physics plugin with the menu item: **Wizards** > **New Physics Plugin**. In the plugin code, you must simply add an ODE *fixed joint* between the *dBodyID* of the robot part and the static environment. This can be implemented like this:

```
#include <ode/ode.h>
#include <plugins/physics.h>

void webots_physics_init() {

  // get body of the robot part
  dBodyID body = dWebotsGetBodyFromDEF("MY_ROBOT_PART");

  // get the matching world
```

```
  dWorldID world = dBodyGetWorld(body);

  // the joint group ID is 0 to allocate the joint normally
  dJointID joint = dJointCreateFixed(world, 0);

  // attach robot part to the static environment: 0
  dJointAttach(joint, body, 0);

  // fix now: remember current position and rotation
  dJointSetFixed(joint);
}

void webots_physics_step() {
  // nothing to do
}

void webots_physics_cleanup() {
  // nothing to do
}
```

You will find the description of Webots physics plugin API in your Reference Manual or on this page[11]. You will find the description about the ODE functions on this page[12].

9.3.6 Should I specify the "mass" or the "density" in the Physics nodes?

It is more accurate to specify the mass if it is known. If you are modeling a real robot it is sometimes possible to find the mass values in the robot's specifications. If you specify the densities, Webots will use the volume of each `boundingObject` multiplied by the density of the corresponding `Physics` node to compute each mass. This may be less accurate because `boundingObjects` are often rough approximations.

9.3.7 How to get a realisitc and efficient rendering?

The quality of the rendering depends on the `Shapes` resolution, on the setup of the `Materials` and on the setup of the `Lights`.

The bigger the number of vertices is, the slower the simulation is (except obviously in `fast` mode). A tradeoff has to be found between these two components. To be efficient, `Shapes` should have a reasonable resolution. If a rule should be given, a `Shape` shouldn't exceed 1000 vertices. Exporting a `Shape` from a CAD software generates often meshes having a huge resolution. Reducing them to low poly meshes is recommended.

[11] `http://www.cyberbotics.com/reference/chapter6.php`
[12] `http://ode-wiki.org/wiki/index.php?title=Manual`

The rendering is also closely related to the `Materials`. To set a `Material` without texture, set only its `Appearance` node. Then you can play with the `diffuseColor` field to set its color (avoid to use pure colors, balancing the RGB components give better results). To set a `Material` with texture, set only its `ImageTexture` node. Eventually, the `specularColor` field can be set to a gray value to set a reflection on the object. The other fields (especially the `ambientIntensity` and the `emissiveColor` fields) shouldn't be modified except in specific situations.

The `color` field of the `ElevationGrid` shouldn't be use for a realistic rendering because it is not affected by the ambient light with the same way as the other `Shapes`.

Here is a methodology to set up the lights:

1. Place the lights at the desired places. Often a single directional light pointing down is sufficient.

2. Set both their `ambientIntensity` and their `intensity` fields to 0.

3. Increase the `ambientIntensity` of the main light. The result will be the appearance of the objects when they are in shadows.

4. Switch on the shadows if required. The shadows are particularily costly, and are strongly related to the `Shapes` resolution.

5. Increase the `intensity` of each lamp.

9.4 Speed/Performance

9.4.1 Why is Webots slow on my computer?

You should verify your graphics driver installation. Please find instructions here section 1.3.

If you are using a laptop computer, please check the power options and make sure you are using the high performance power plan.

On Ubuntu (or other Linux) we do also recommend to deactivate *compiz* (**System** > **Preferences** > **Appearance** > **Visual Effects = None**). Depending on the graphics hardware, there may be a huge performance drop of the rendering system (up to 10x) when *compiz* is on.

9.4.2 How can I change the speed of the simulation?

There are several ways to increase the simulation speed:

1. Use the **Run** button (Webots PRO only). This button runs the simulation as fast as possible using all the available CPU power. Otherwise, using the **Real-Time** running mode, Webots may not be using all the available CPU power in order to obtain a simulation speed that is close to the speed of the real world's phenomena.

2. Use the **Fast** button (Webots PRO only). This button runs the simulation as fast as possible using all the available CPU power. In this mode the simulation speed is increased further by leaving out the graphics rendering, hence the 3d window is black.

3. Increase the value of `WorldInfo.basicTimeStep`. This field sets the granularity of the physics simulation. With a higher `WorldInfo.basicTimeStep`, the simulation becomes faster but less accurate. With a lower `WorldInfo.basicTimeStep`, the simulation becomes slower but more accurate. There is an additional restriction: `WorldInfo.basicTimeStep` must be chosen such as to be an integer divisor of the *control step* which is the value passed as parameter to the `wb_robot_step()` (or equivalent) function.

4. Decrease the value of `WorldInfo.FPS`. This field represents the maximum rate at which the 3D display of the main windows is refreshed. With a lower value, the simulation becomes faster but more flickering. With a higher value, the simulation becomes slower but less flickering.

5. Try changing the value of `WorldInfo.optimalThreadCount`. This field specifies how many threads are used to simulate the physics of the world. Depending on the world you can get a better performance by reducing or increasing this value. In general it is better to have a low number of threads for simple worlds and a bigger number of threads for complex worlds that include several robots physically independent from each other.

6. Disable unnecessary shadows. Webots uses a lot of CPU/GPU power to compute how and where the objects shadows are cast. But shadows are irrelevant for most simulation unless they should explicitly be seen by Cameras. Unnecessary shadows can be disabled by unchecking the `castShadows` field of light nodes: `PointLight`, `SpotLight`, or `DirectionalLight`.

7. Simplify your simulation by removing unnecessary objects. In particular, try to minimize the number of `Physics` nodes. Avoid using a `Solid` nodes when a `Transform` or a `Shape` would do the trick.

8. Simplify the `boundingObject`s to increase the speed of the collision detection. Replace complex primitives, like `Cylinder`, `IndexedFaceSet` and `ElevationGrid` by simpler primitives, like `Sphere`, `Capsule`, `Box` and `Plane`. Avoid using a composition of primitives (in a `Group` or a `Transform`) when a single primitive would do the trick.

Chapter 10

Known Bugs

This chapter lists the bugs known by Cyberbotics. They are not planned to be resolved on the short term but possible workarounds are explained.

10.1 General bugs

10.1.1 Intel GMA graphics cards

Webots should run on any fairly recent computer equipped with a nVidia or ATI graphics card and up-to-date graphics drivers. Webots is not guaranteed to work with Intel GMA graphics cards: it may crash or exhibit display bugs. Upgrading to the latest versions of the Intel graphics driver may help resolve such problems (without any guarantee). Graphics drivers from Intel may be obtained from the Intel download center web site[1]. Linux graphics drivers from Intel may be obtained from the Intel Linux Graphics web site[2].

10.1.2 Virtualization

Because it highly relies on OpenGL, Webots may not work properly in virtualized environments (such as VMWare or VirtualBox) which often lack a good OpenGL support. Hence, Webots may exhibit some display bugs, run very slowly or crash in such environments.

10.1.3 Collision detection

Although collision detection works well generally well, `Cylinder-Cylinder`, `Cylinder-Capsule`, `IndexedFaceSet-IndexedFaceSet` and `IndexedFaceSet-Cylinder`

[1] `http://downloadcenter.intel.com`
[2] `http://intellinuxgraphics.org`

collision detection may occasionaly yield wrong contact points. Sometimes the contact points may be slightly off the shape, therefore causing unrealistic reaction forces to be applied to the objects. Other times there are too few contact points, therefore causing vibration or instabilities.

10.1.4 Orientation dependent friction

Although the friction model of ODE is very accurate, the true friction cone is approximated by a linearized version which can introduce some orientation specific artifacts. It is for example possible that an object slips more easily on another object in some direction than in some other, even if the friction coefficients are set to be symmetric. However, in most of the cases it is possible to get rid of these effects by tuning correctly the friction parameters.

10.2 Mac OS X

10.2.1 Matlab and robot plugins

The controllers and the robot plugins (e.g. the robot windows) are sharing the same process. Generally this mechanism is working well, but some instabilities (crashes and warnings) may occur when a robot uses a Matlab controller and a robot window at the same time. This is due to some conflicts between the Qt libraries used by Matlab and the one used by Webots.

10.3 Linux

10.3.1 Window refresh

It may happen that the main window of Webots is not refreshed properly and appears blank at startup or upon resize or maximization. This is caused by a conflict between the Compiz window manager and OpenGL. Simply disabling Compiz should fix such a problem. This can be achieved on Ubuntu Linux from the System menu: **Preferences** > **Appearance** > **Visual Effects** > **None**.

10.3.2 ssh -x

There are known issues about running Webots over a `ssh -x` (x-tunneling) connection. This problem is not specific to Webots but to most GLX (OpenGL on the X Window system) applications that use complex OpenGL graphics. We think this is caused by incomplete or defective implementation of the GLX support in the graphics drivers on Linux. It may help to run the `ssh -x` tunnel across two computers with the same graphics hardware, e.g., both nVidia or both ATI. It also usually works to use Mesa OpenGL on both sides of the `ssh -x` tunnel, however this solution is extremely slow.